VAMS TIM#5

METRON AVIATION

Technologies Enabling All-Weather Maximum Capacity by 2020
Phase 3 Assessment Results

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Metron Aviation, Inc
March, 2005

Core Idea Triad:

Situation Awareness, Coordination, and Information Transfer

Flexible Traffic Management Considering Weather Constraints

Prediction (Coupled Weather and Traffic Prediction)

Core Idea Triad:

Phase 3 ACES Assessments Focused on this Core Idea

Situation Awareness, Coordination, and Information Transfer

Flexible Traffic Management Considering Weather Constraints

Prediction (Coupled Weather and Traffic Prediction)

Goals for ACES Phase 3 Assessment:

- **Analyze the NAS-wide effects of two important elements of the All-Weather Capacity Increasing Concept:**

  Core Idea 1.1 – Pre-Flight Planning (GDPs) to Manage Airport Rates

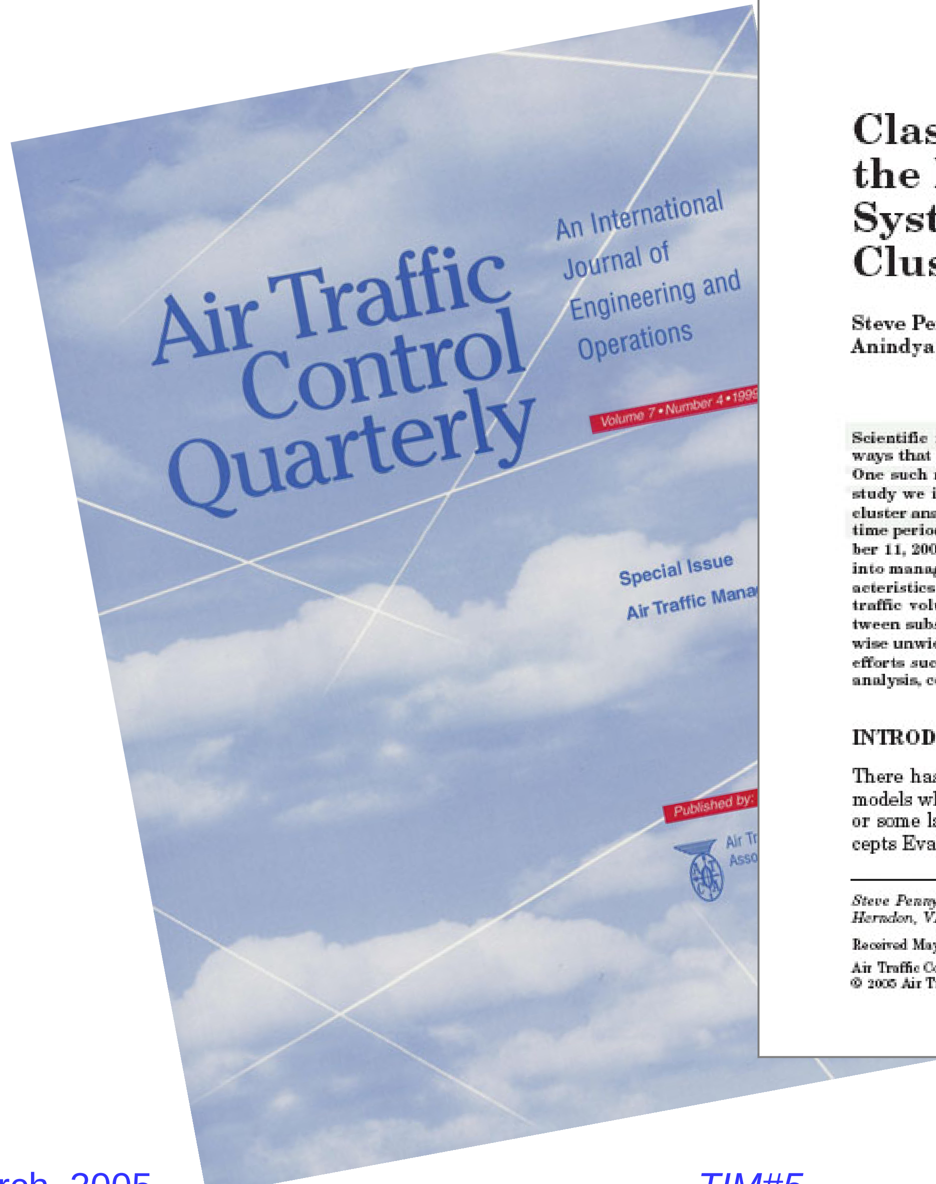
  Core Idea 1.4 – Weather Avoidance Algorithms for Transition Airspace

- **Roll up ACES results to estimate annual NAS-wide benefits for current and future traffic levels**

- **Determine additional ACES functionality needed to model remaining elements of the All-Weather Concept**

- **Document bugs and unexpected behavior of existing ACES functionality**

Types of Days in the NAS:



Classification of Days in the National Airspace System Using Cluster Analysis

Steve Penny, Robert Hoffman, Jimmy Krozel, and Anindya Roy

Scientific methods can describe the National Airspace System (NAS) in ways that provide intuitive insights into its operation and performance. One such method is classification and analysis of historical data. In this study we identify key metrics representing the NAS as a whole, and use cluster analysis techniques to classify days in the NAS spanning a four-year time period. Data are analyzed and compared before and after the September 11, 2001 national tragedy. Through classification, we reduce this data into manageable and meaningful subsets. Each subset has dominant characteristics that exemplify typical behaviors in the NAS, primarily based on traffic volume and weather. The data are then analyzed within and between subsets in order to gain information and knowledge from an otherwise unwieldy superset. The results of such an analysis can be utilized for efforts such as the testing and validation of NAS simulations, NAS trend analysis, cost/benefit annualization, and quality assurance.

INTRODUCTION

There has been considerable work of late in large-scale simulation models whose domain is the entire National Airspace System (NAS), or some large portion of it. For example, NASA's Future ATM Concepts Evaluation Tool (FACET) [Bilimoria, et al., 2001] and NASA's

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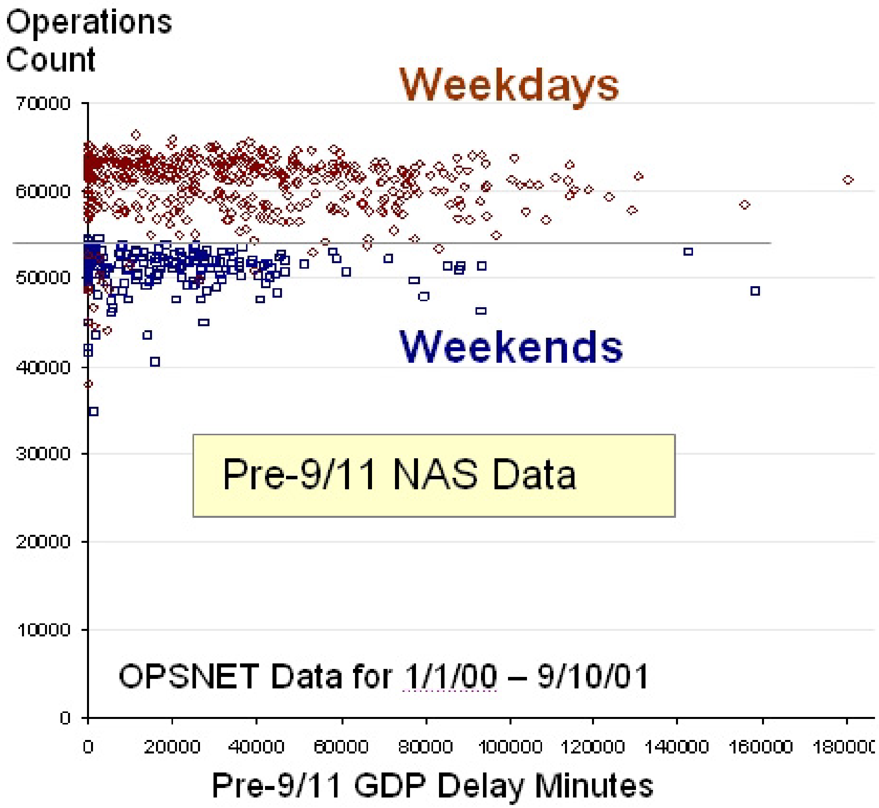
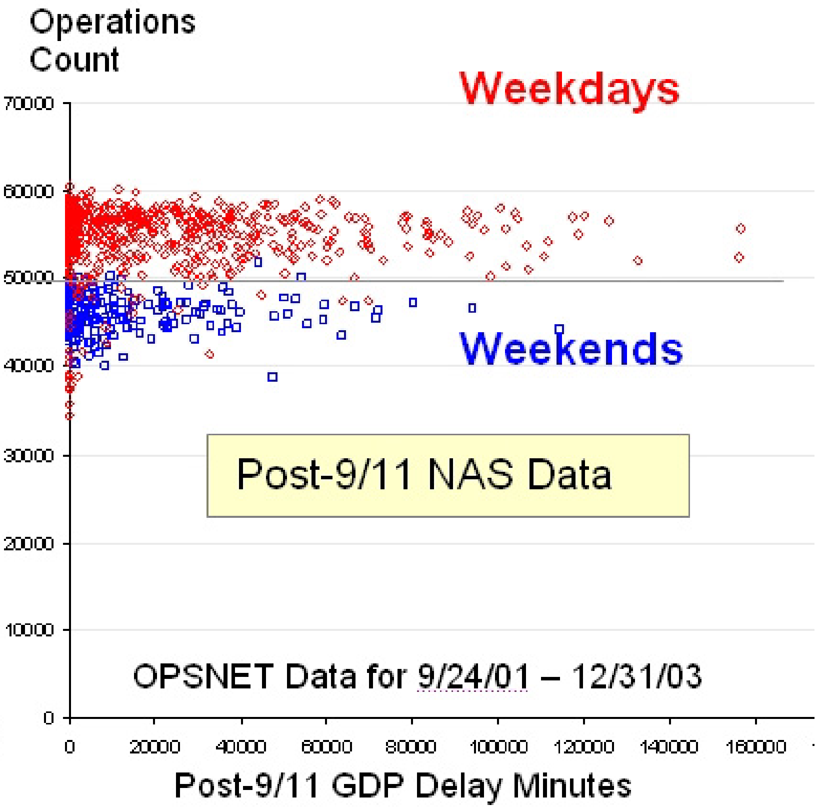
CCC 1064-3818/95/030163-20

1

Types of Days in the NAS:

- **Analysis of 2000-2003 NAS data**
- **Cluster Analysis – What are the different types of weather days?**





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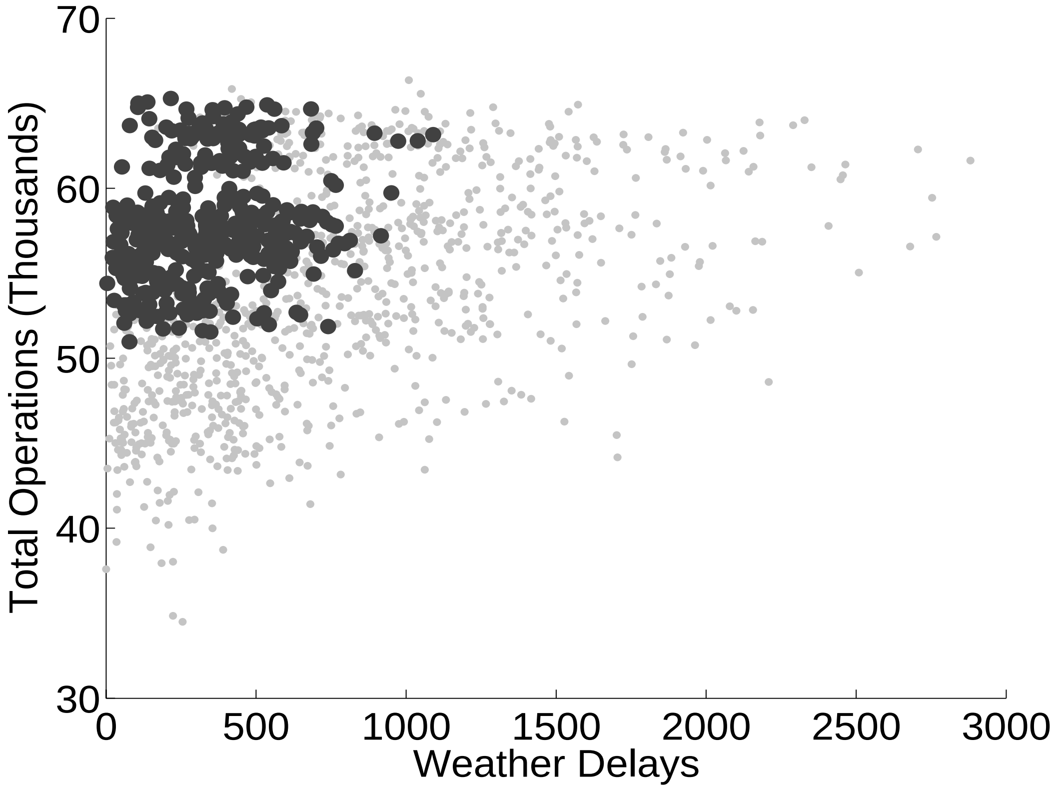
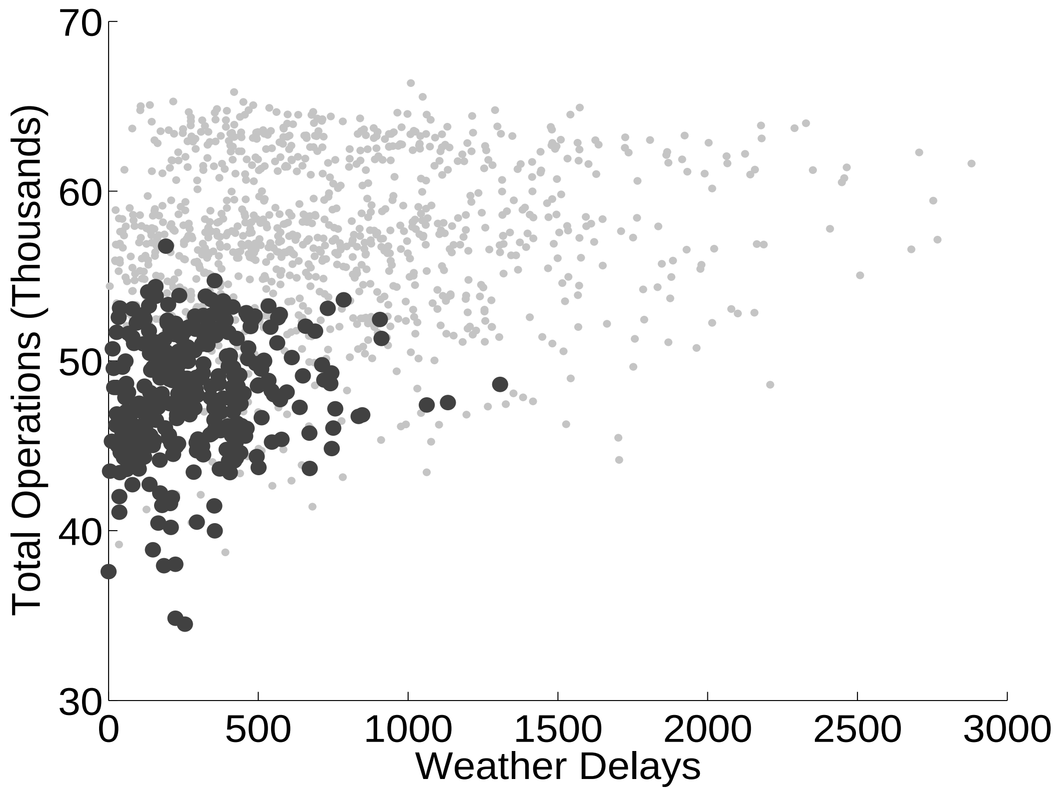
Cluster 1:

- **High Volume, No Weather Effects**



Cluster 2:

- **Low Volume, No Weather Effects**



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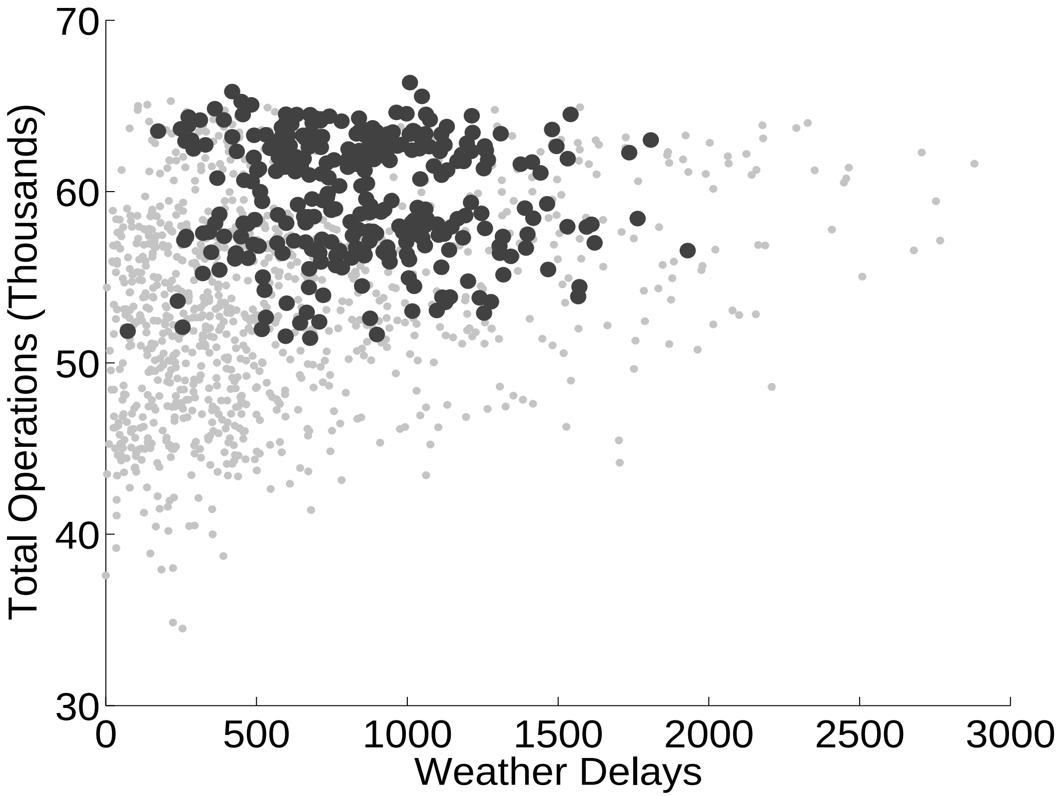
Cluster 3:

- **High Volume, Medium Delay due to Weather**



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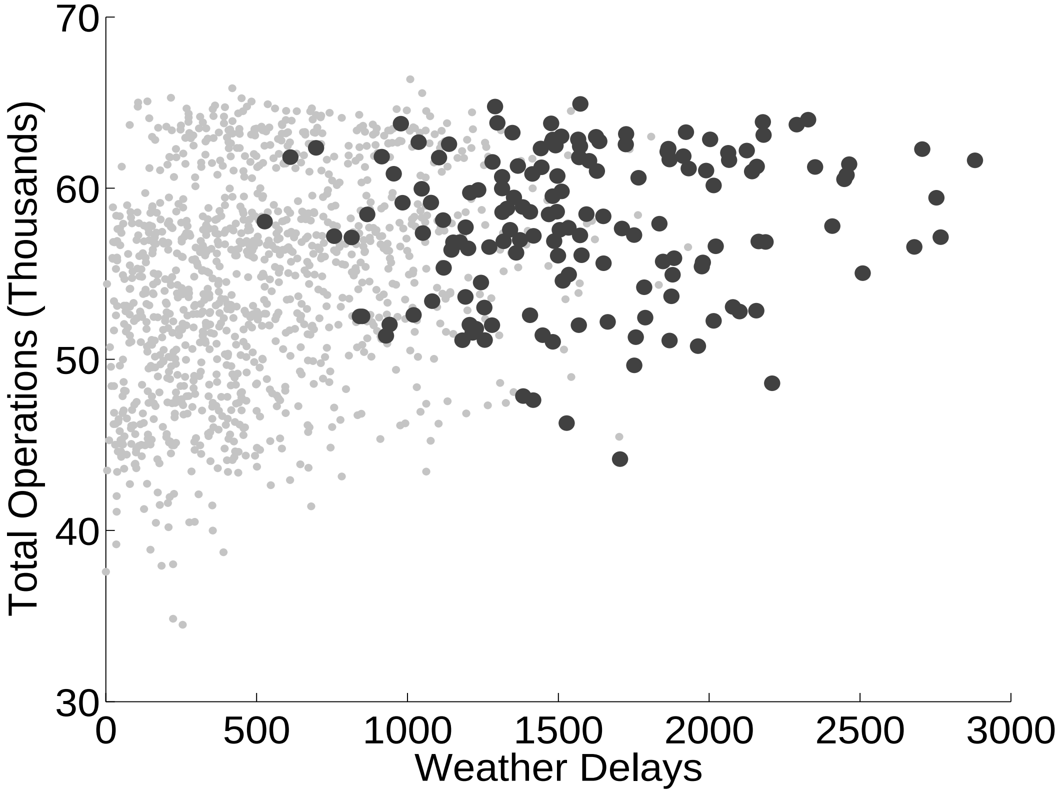
Cluster 4:

- **High Weather Related Delays, Low GS Delays**



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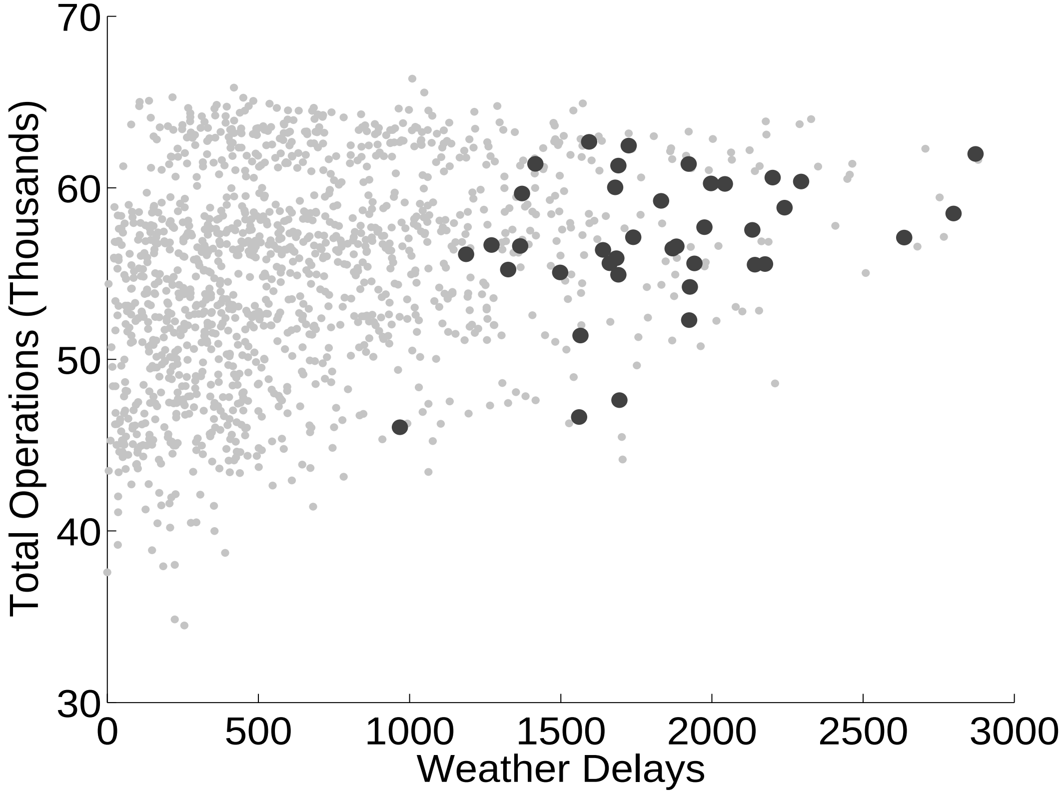
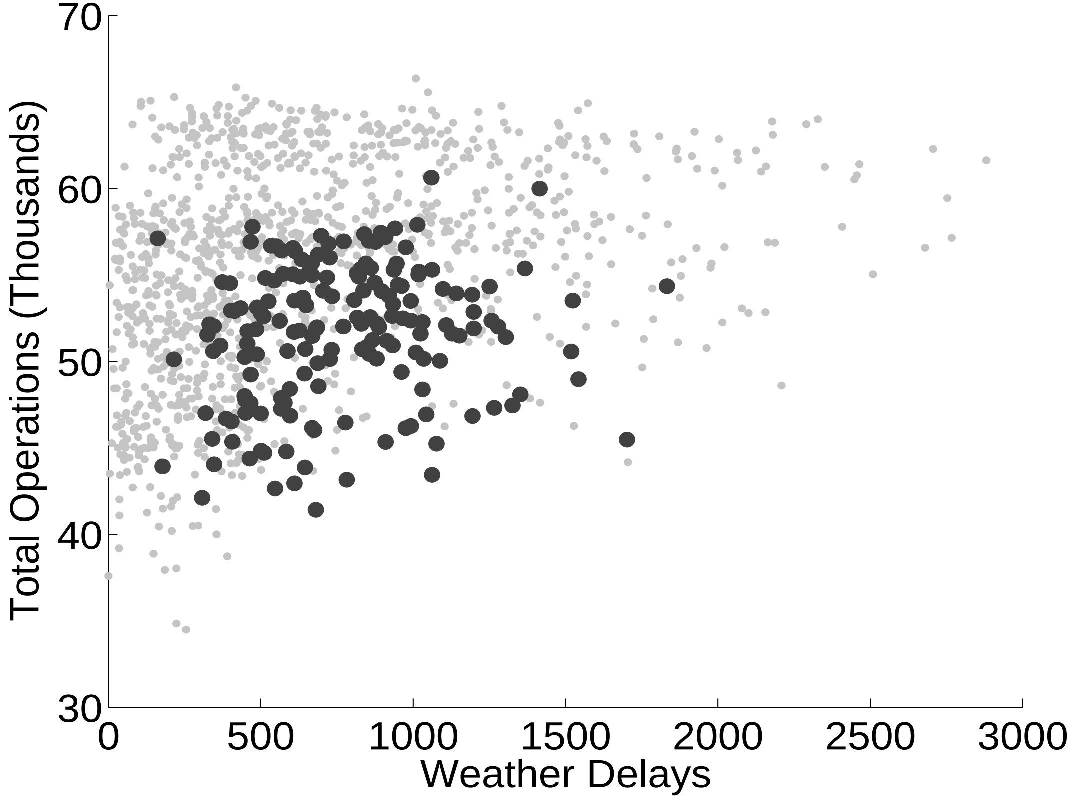
Cluster 5:

- **High Weather Related Delays; High GS Delays**



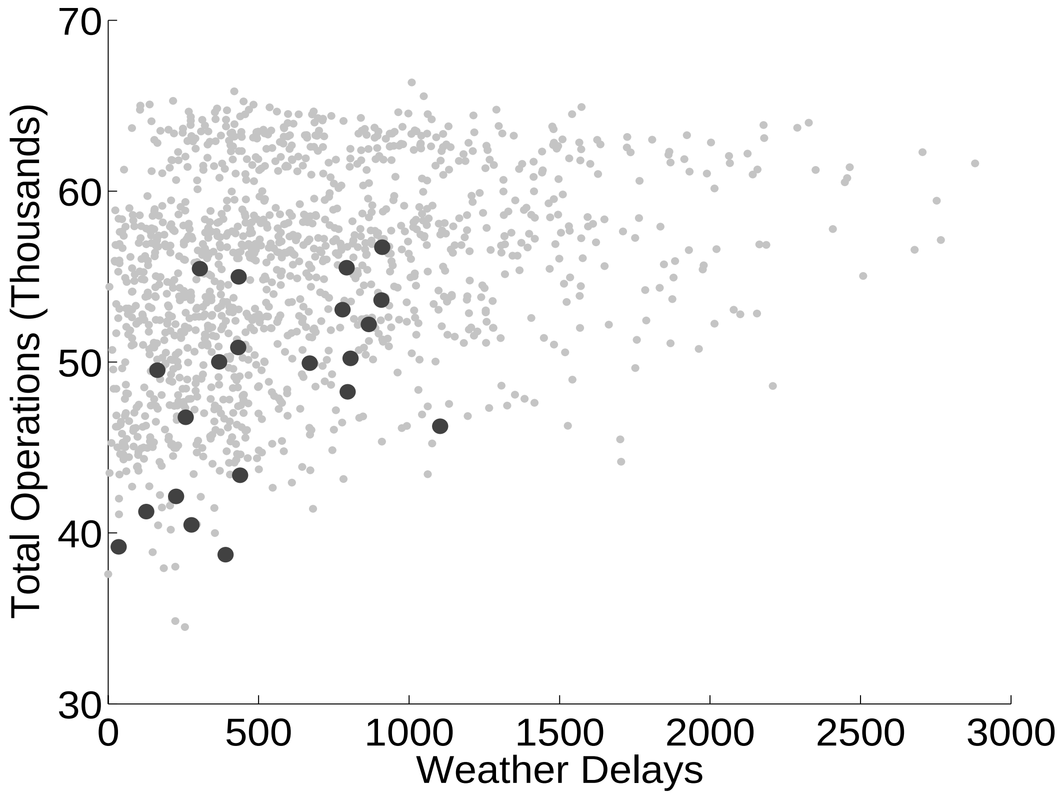
Cluster 6:

- **Low Volume, Medium Weather Related Delays**



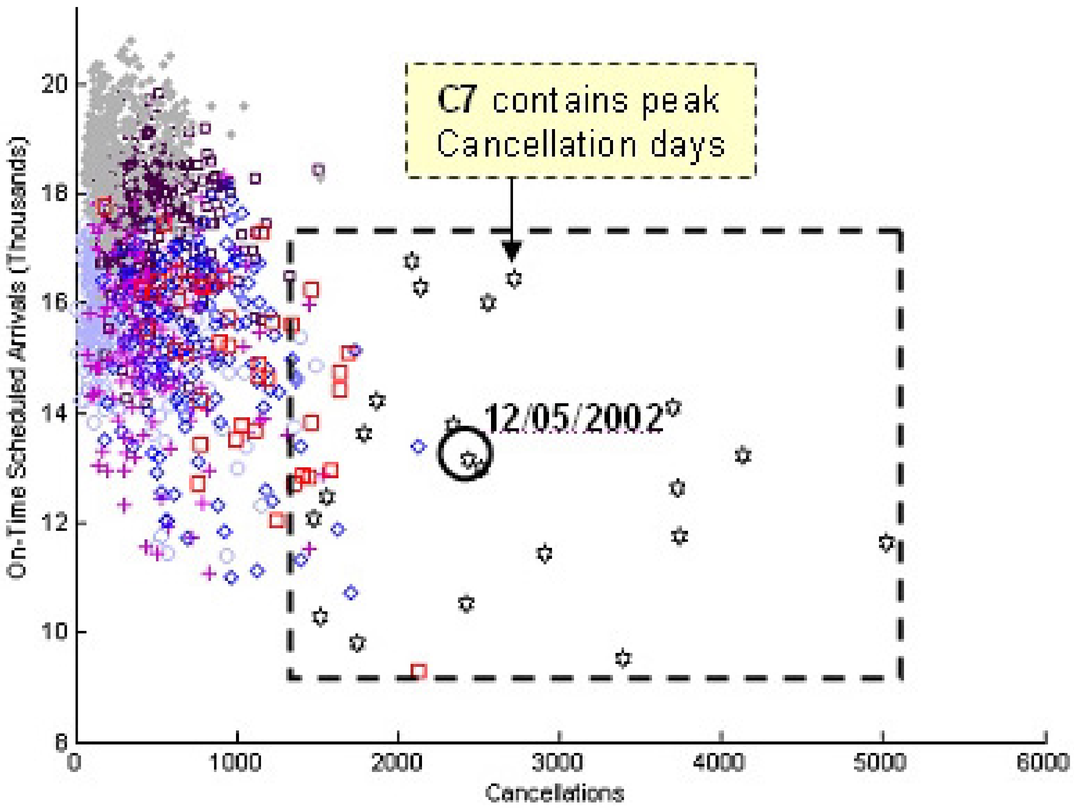
Cluster 7:

- **Peak Cancellation Days**



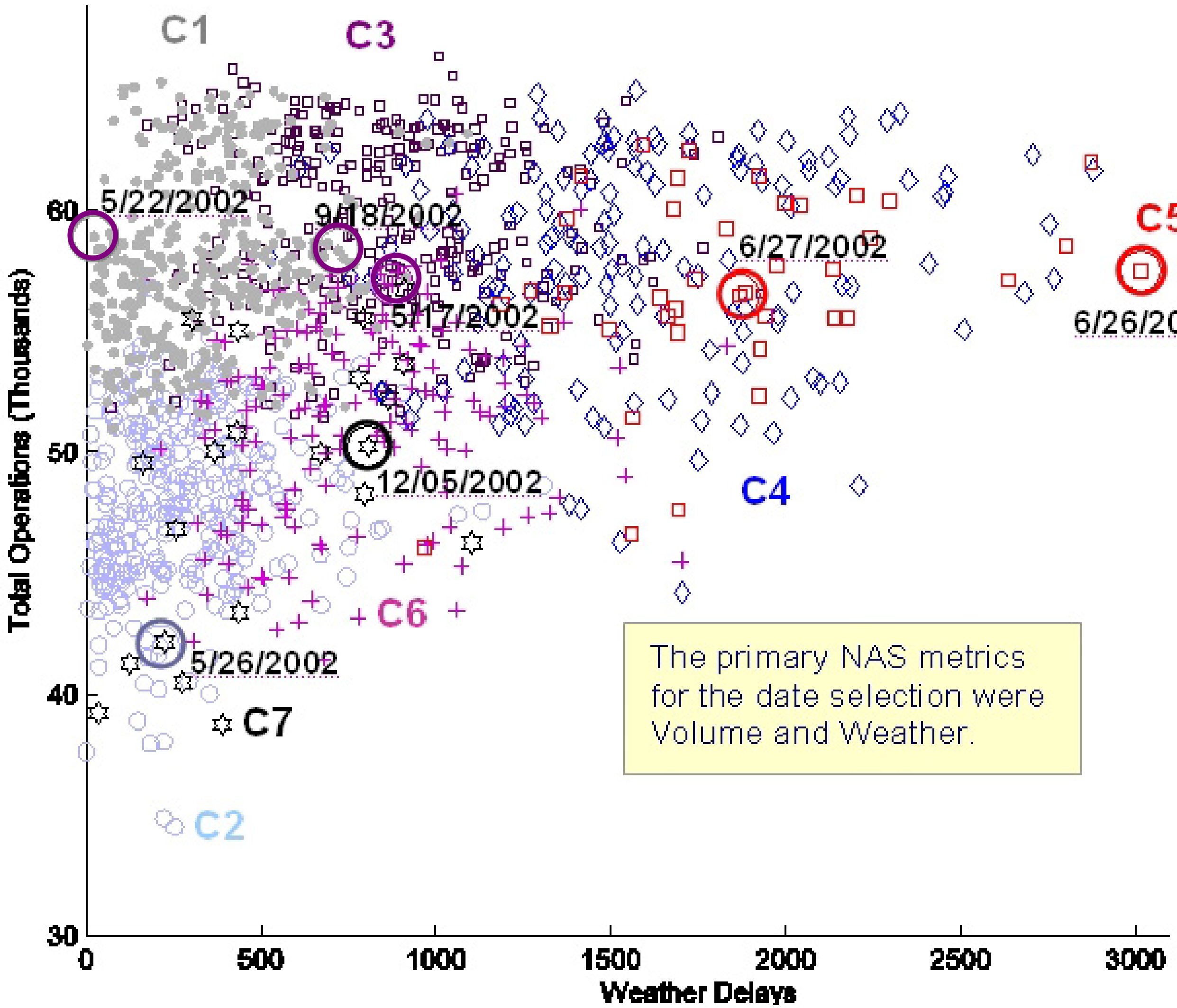
Cluster 7: (Another Projection)

- Cancellations vs On-Time Scheduled Arrivals



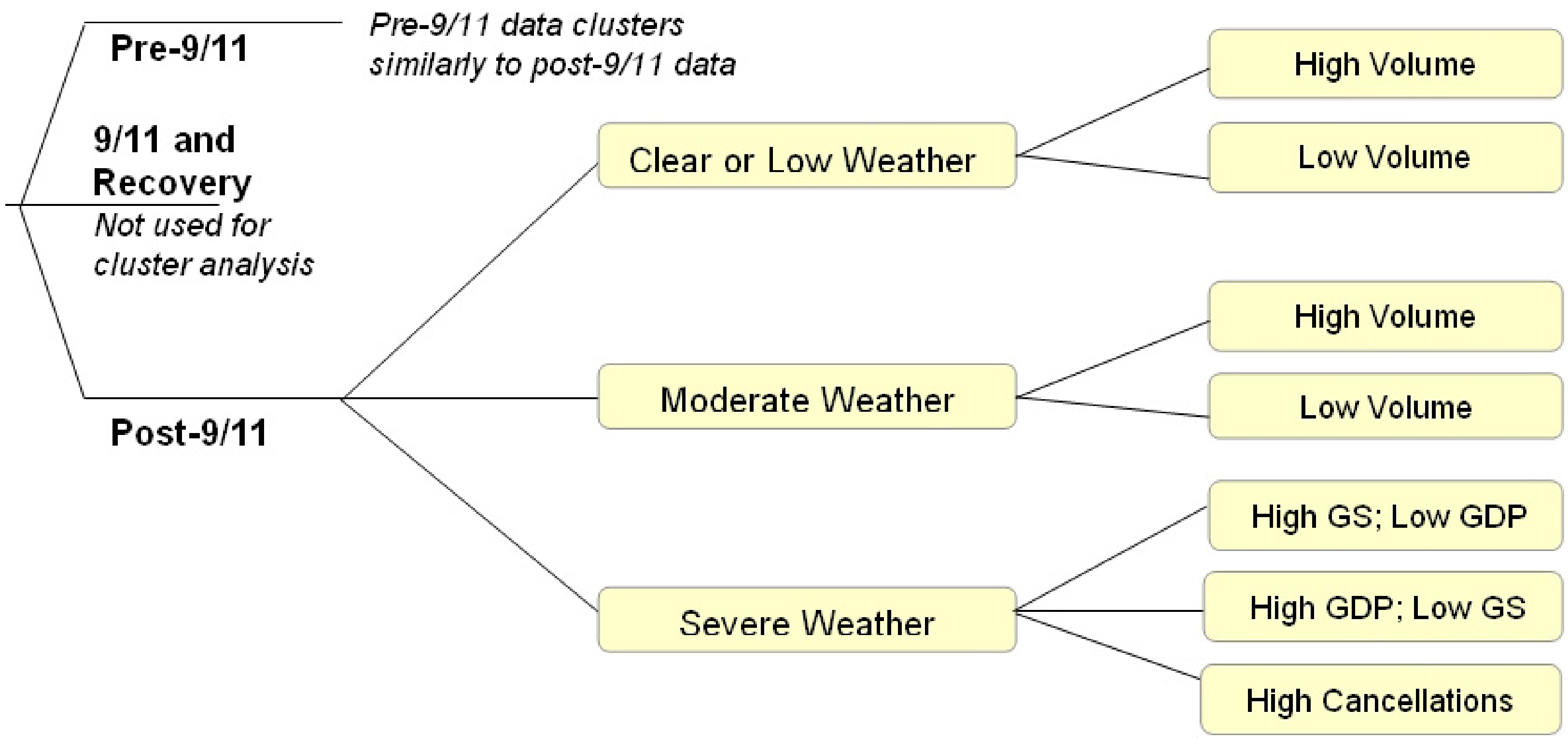
Types of Days in the NAS:

- **Weather Related Delays**



The primary NAS metrics for the date selection were Volume and Weather.

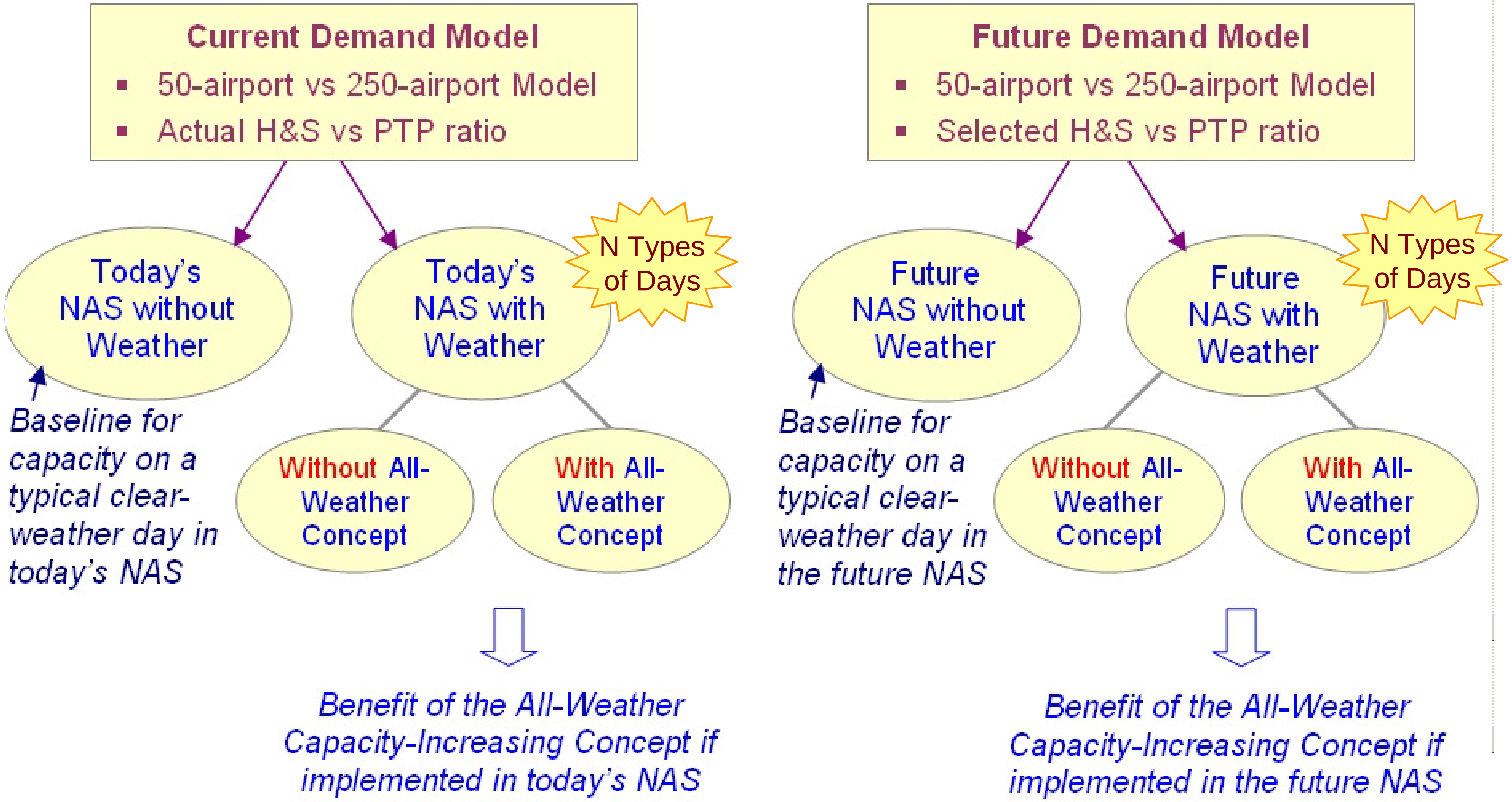
Dendrogram:


Pre-9/11
Pre-9/11 data clusters similarly to post-9/11 data
9/11 and Recovery
Not used for cluster analysis
Post-9/11
Clear or Low Weather
Moderate Weather
Severe Weather
High Volume
Low Volume
High Volume
Low Volume
High GS; Low GDP
High GDP; Low GS
High Cancellations

Days of Interest:

Date	Day of Week	Cluster	Vol	Weather Effects	Description
5/17	F	6	High	Mod/High	ACES Simulation High Volume Baseline Day - On-Time arrival counts are on par with 5/26, even though volume is much higher
5/22	W	1	High	Low	Wx NRA Clear/Low Weather Type Day - High Volume, Low Delay
5/26	Su	2	Low	Low	ACES Simulation Volume Trend Day (Chosen in particular because it was identified as a low volume day) Low Volume, Low Delay
6/26	W	5 (4)	High	Severe	Wx NRA Severe Weather Type Day - Convective Activity - Medium GSs, High GDPs This puts it on the edge between Clusters C4 & C5
6/27	Th	5	High	Severe	Wx NRA Severe Weather Type Day - Convective Activity - High GSs, Low GDPs
9/18	W	1 (3)	High	Mod/Low	Wx NRA Moderate Weather Type Day - This date is on the edge between Clusters C1 & C3
12/05	Th	7	Low	Severe	Wx NRA Severe Weather Type Day - Major snowstorm impacts areas from Oklahoma to Virginia and Tennessee on 12/4. On 12/5 it sweeps into the Northeast causing snow and icing. High Cancellations and GDP delays experienced.

Approach:



- **Assume nature of convective weather is the same in 2020**

Approach to Annualization for NAS-Wide Benefits:

- **Study N types of days & Measure Performance Metrics in ACES**
  - **2002 vs 2020**
- **Roll up a (Frequency-based) weighted sum of the Performance Metrics over the different types of days**

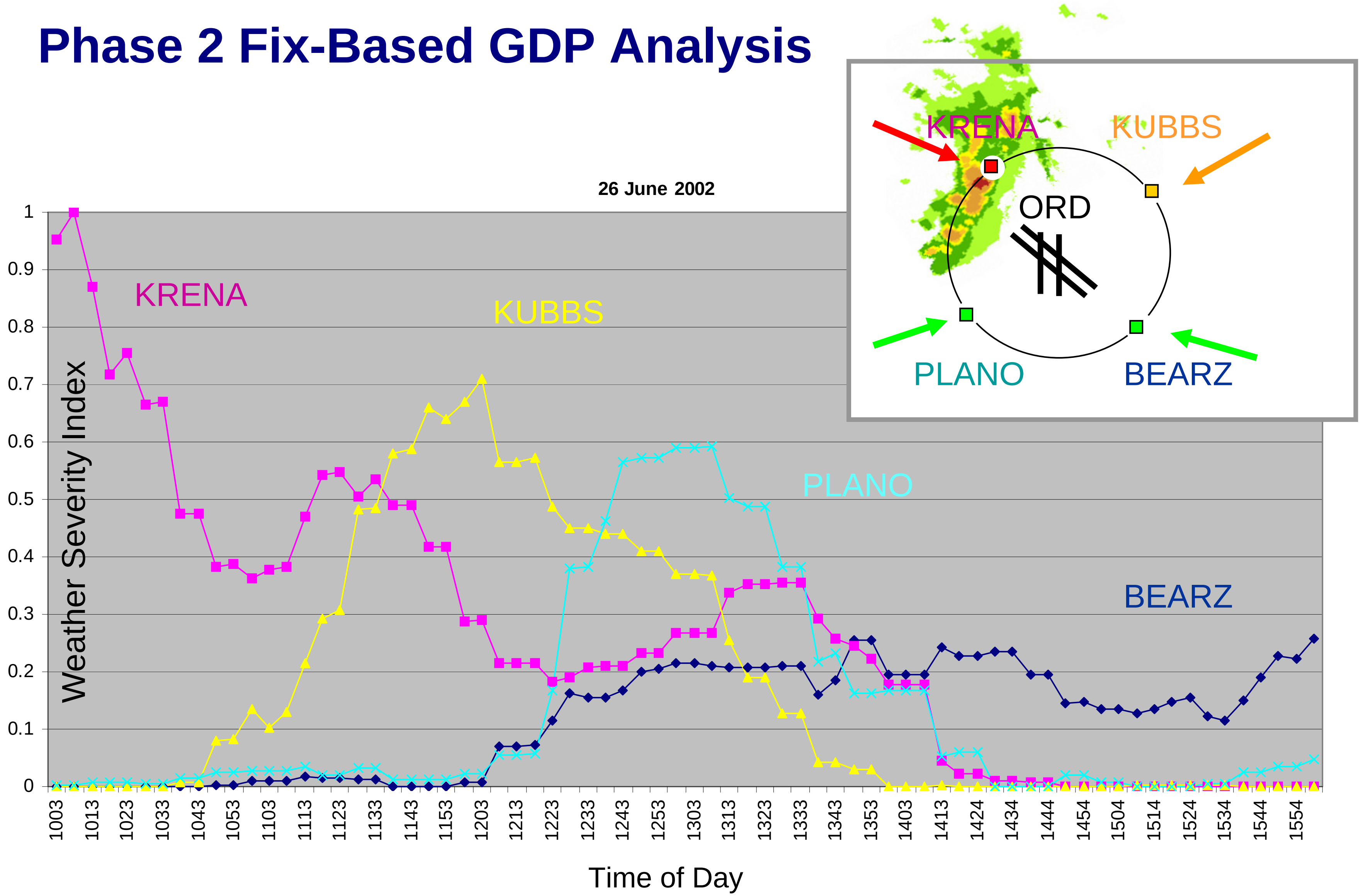
$$\text{Annualized Cost} = \underbrace{0.338C_1()}_{\text{Type 1 Days}} + \underbrace{0.268C_2()}_{\text{Type 2 Days}} + \underbrace{0.166C_3()}_{\text{Type 3 Days}} + \underbrace{0.130C_4()}_{\text{Type 4 Days}} + \underbrace{0.063C_5()}_{\text{Type 5 Days}} + \underbrace{0.025C_6()}_{\text{Type 6 Days}} + \underbrace{0.010C_7()}_{\text{Type 7 Days}}$$

Cluster	Cluster Name	Number of Days			Frequency (%)		
		2002	2003	Total	2002	2003	Total
1	Clear Weather High Volume Type Day	125	122	247	34.2	33.4	33.8
2	Clear Weather Low Volume Type Day	113	83	196	31.0	22.7	26.8
6	Moderate Weather Low Volume Type Day	45	76	121	12.3	20.8	16.6
3	Moderate Weather High Volume Type Day	58	37	95	15.9	10.1	13.0
4	Severe Weather with Low GSs; High GDPs	14	32	46	3.8	8.8	6.3
5	Severe Weather with High GSs; Low GDPs	9	9	18	2.5	2.5	2.5
7	Severe Weather with High Cancellations	1	6	7	0.3	1.6	1.0

Core Idea 1.1: Pre-Flight Planning to Manage Airport Flow Rates

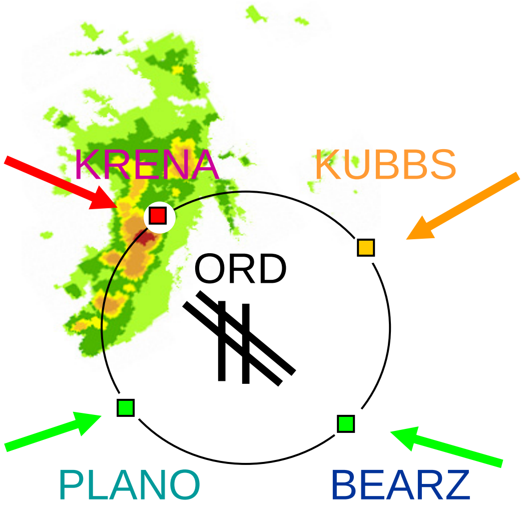
- **Long-Term Probabilistic Weather Forecasts**
- **GDPs**
- **Fix-Based GDPs (w&w/o En Route Cornerpost Swaps)**
- **Distance-Based 1st Tier, 2nd Tier GDPs**
- **Multi-Airport GDPs**
- **Specialty GDPs (e.g., SFO Fog Burnoff, FCA-Based GDP)**
- **Cancellations model based on line of flight**
- **User Priorities and Constraints**

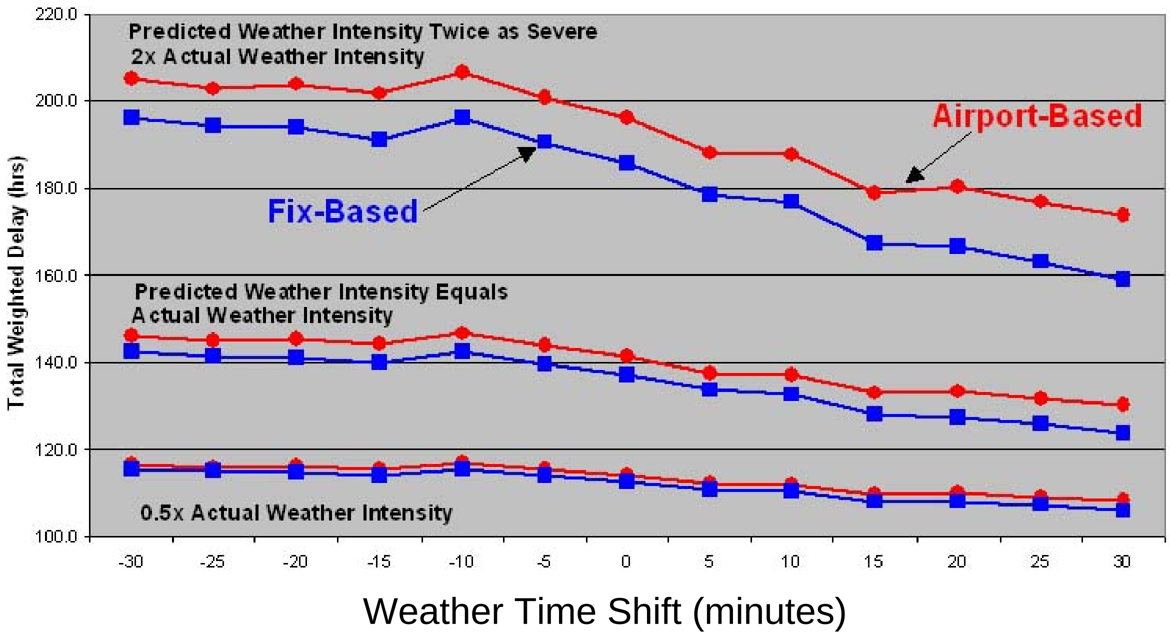
Phase 2 Fix-Based GDP Analysis



Airport vs Fix-based GDPs

- What could we do with improved weather prediction accuracy and pre-flight GDPs?



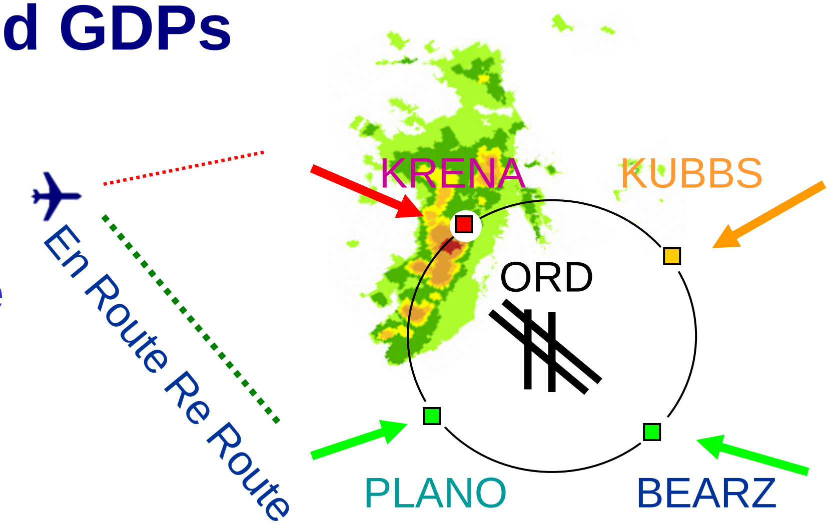


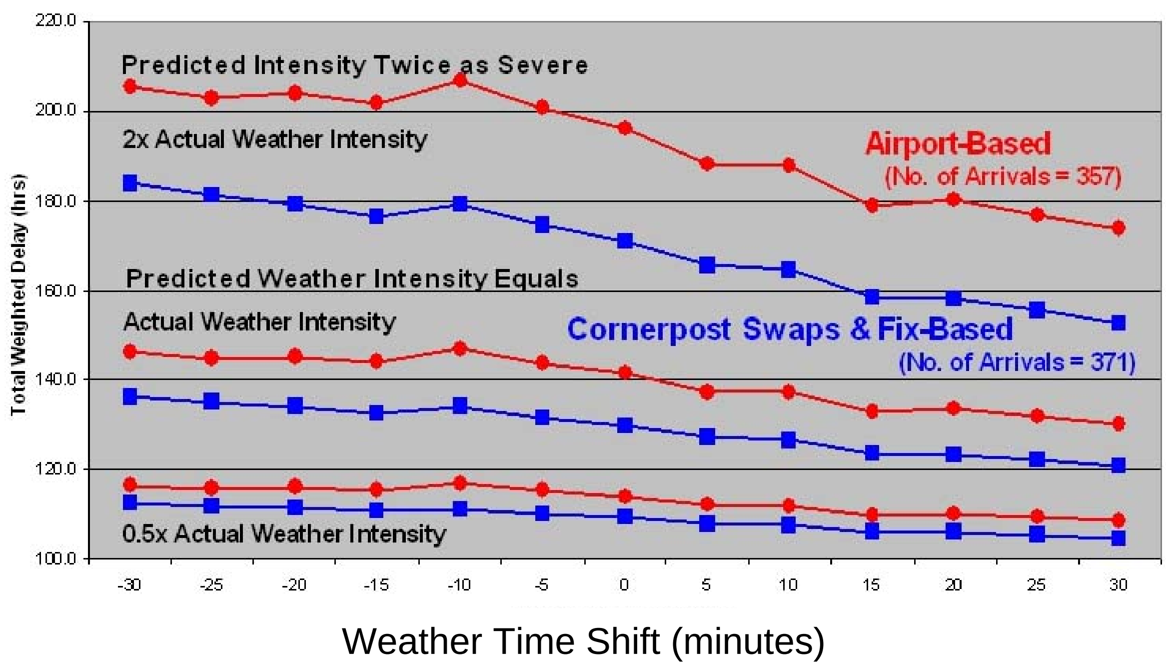
ORD simulation with weather prediction accuracy varied spatially and temporally in a controlled experiment.

A positive weather time shift denotes forecast weather later than actual weather.

Airport GDPs vs Fix-based GDPs with Cornerpost Swaps

- What if we could plan cornerpost swaps en route during the GDP implementation?





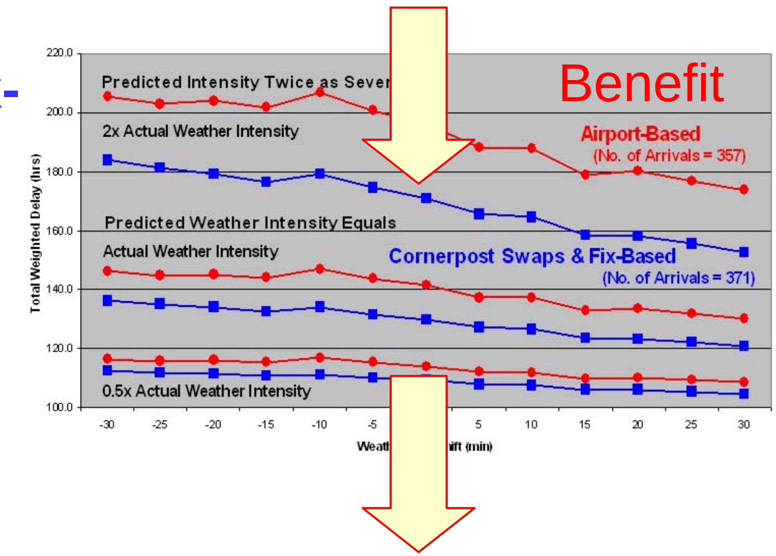
ORD simulation with weather prediction accuracy varied spatially and temporally in a controlled experiment.

A positive weather time shift denotes forecast weather later than actual weather.

Core Idea 1.1 –
Pre-Flight Planning to Manage Airport Flow Rates

- **Use airport arrival rates for GDPs on weather days from ATCSCC logs**
- **Model future GDPs by scaling arrival rate by airport's capacity growth**
- **Model improved GDPs (such as fix-based GDPs and fix-based GDPs with cornerpost swaps):**
  - **Increasing Airport AARs**
  - **Maintaining the number of affected aircraft**
- **Use AirportState data file to create associated XFR airport states**

2002 vs 2020 AARs



ACES XFR Data

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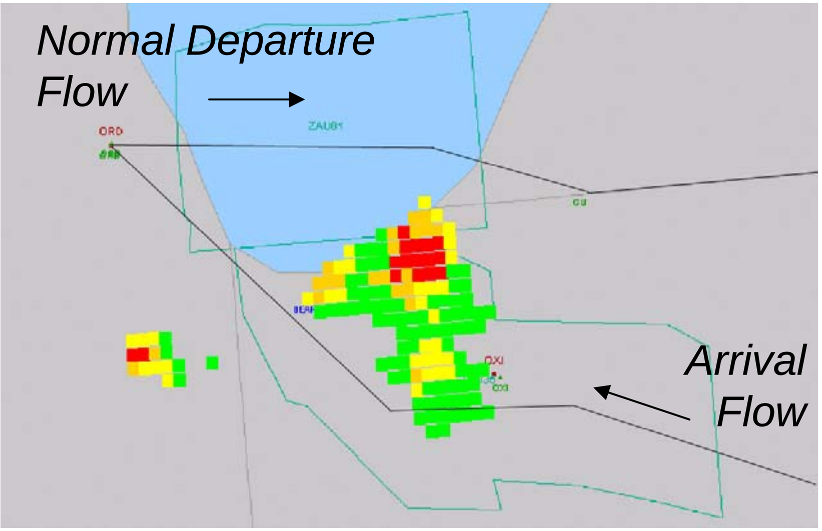
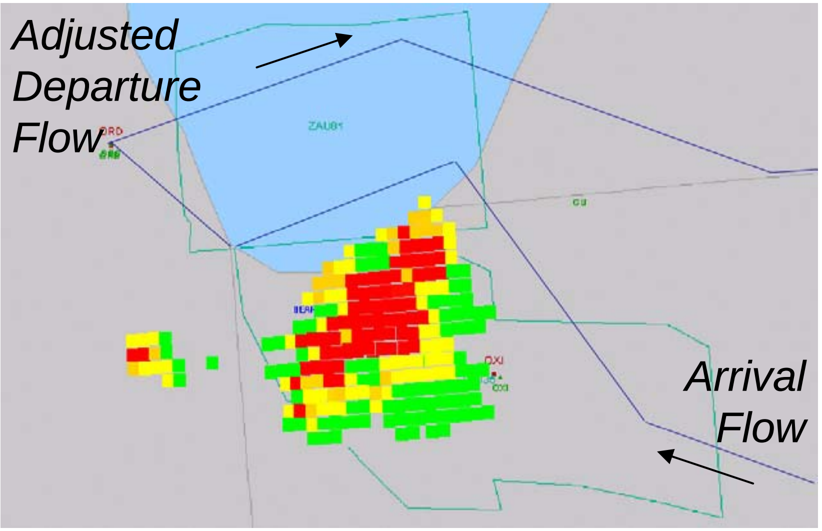
Core Idea 1.4: Weather Avoidance Algorithms for the Transition Airspace

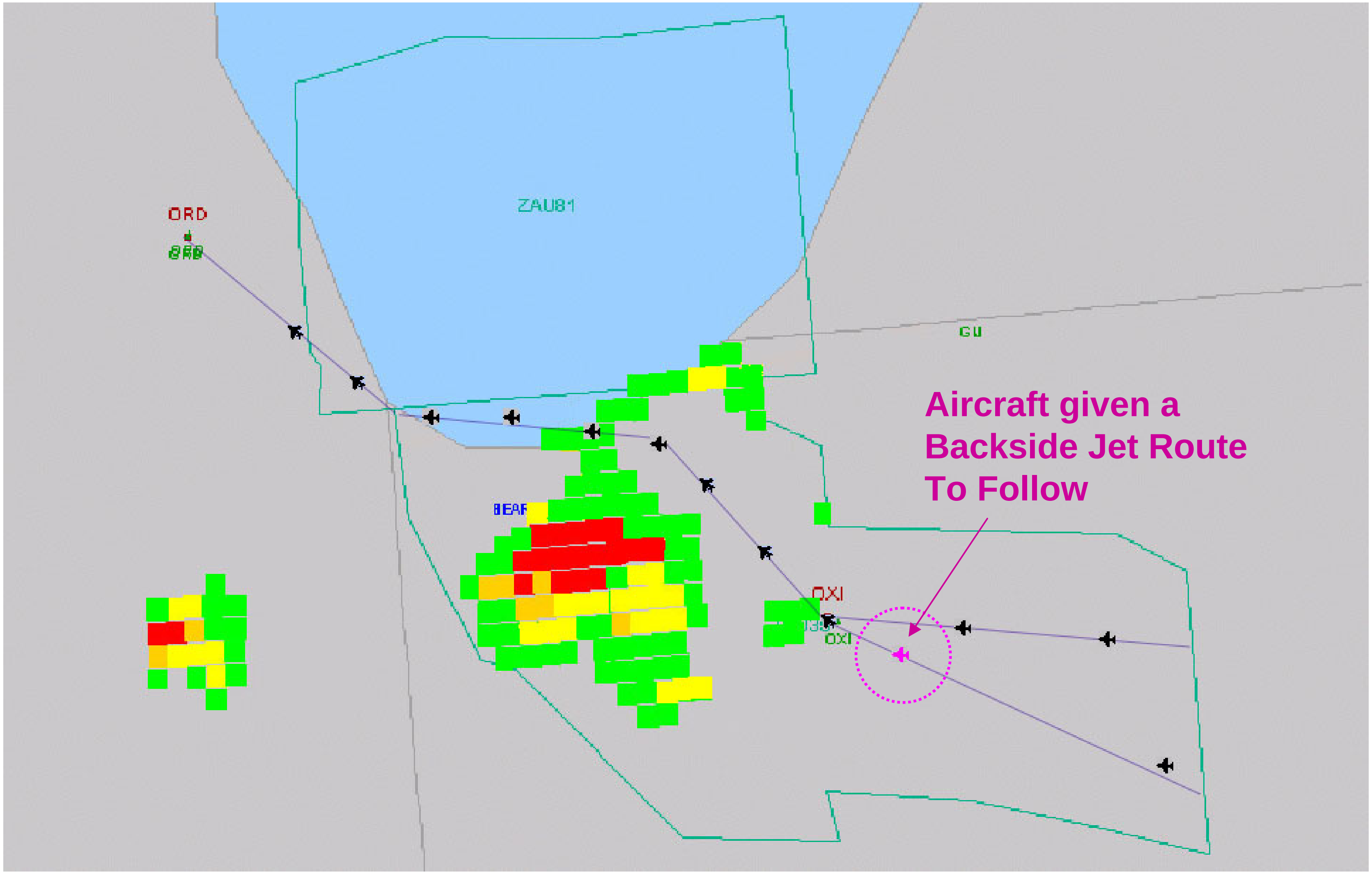




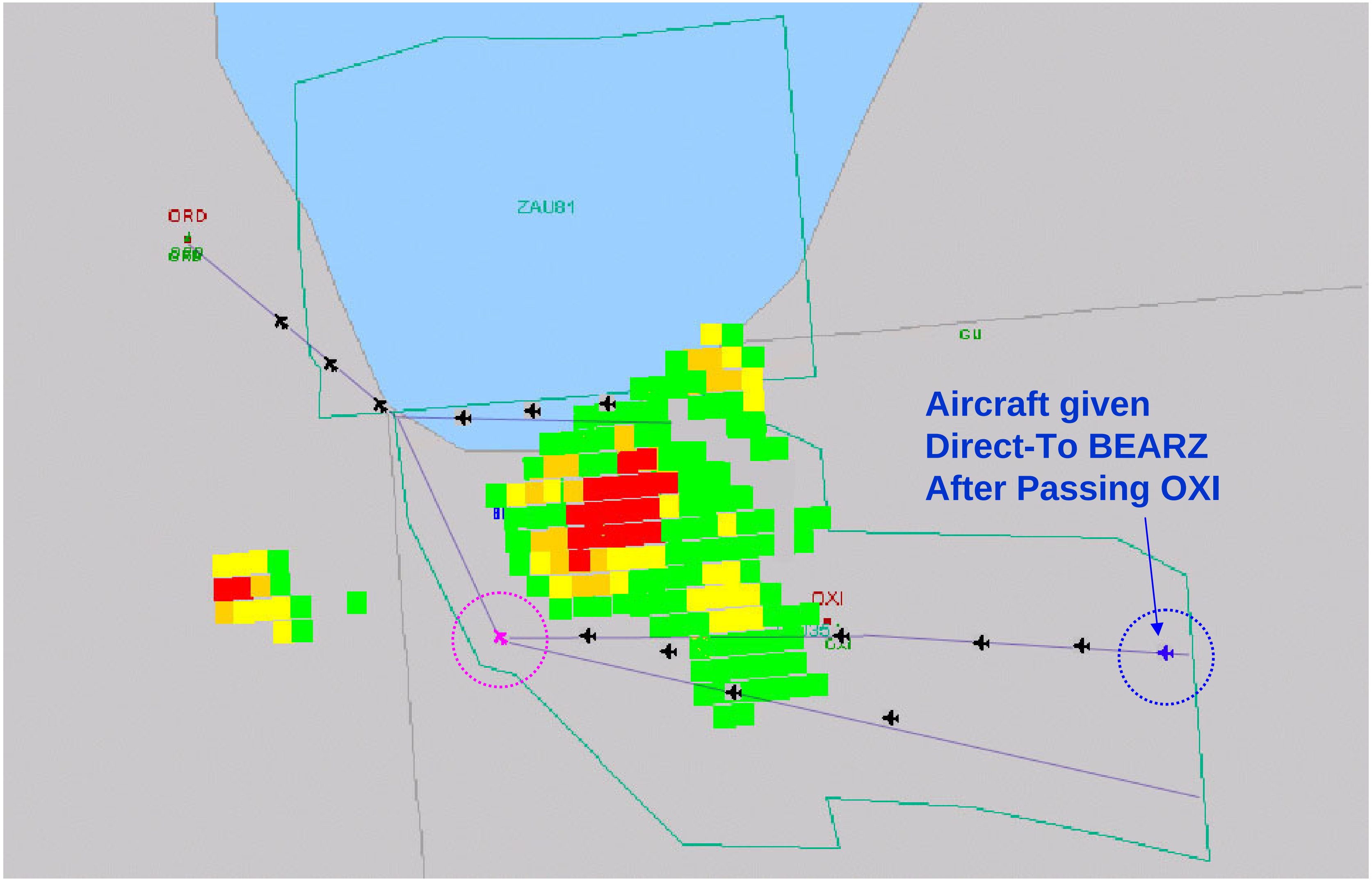
Departure Flow Unaffected by Arrival Flow Weather Avoidance Route

Departure Flow Re-Designed with Arrival Flow Weather Avoidance Route

Example Transition Airspace (1)



Example Transition Airspace (2)



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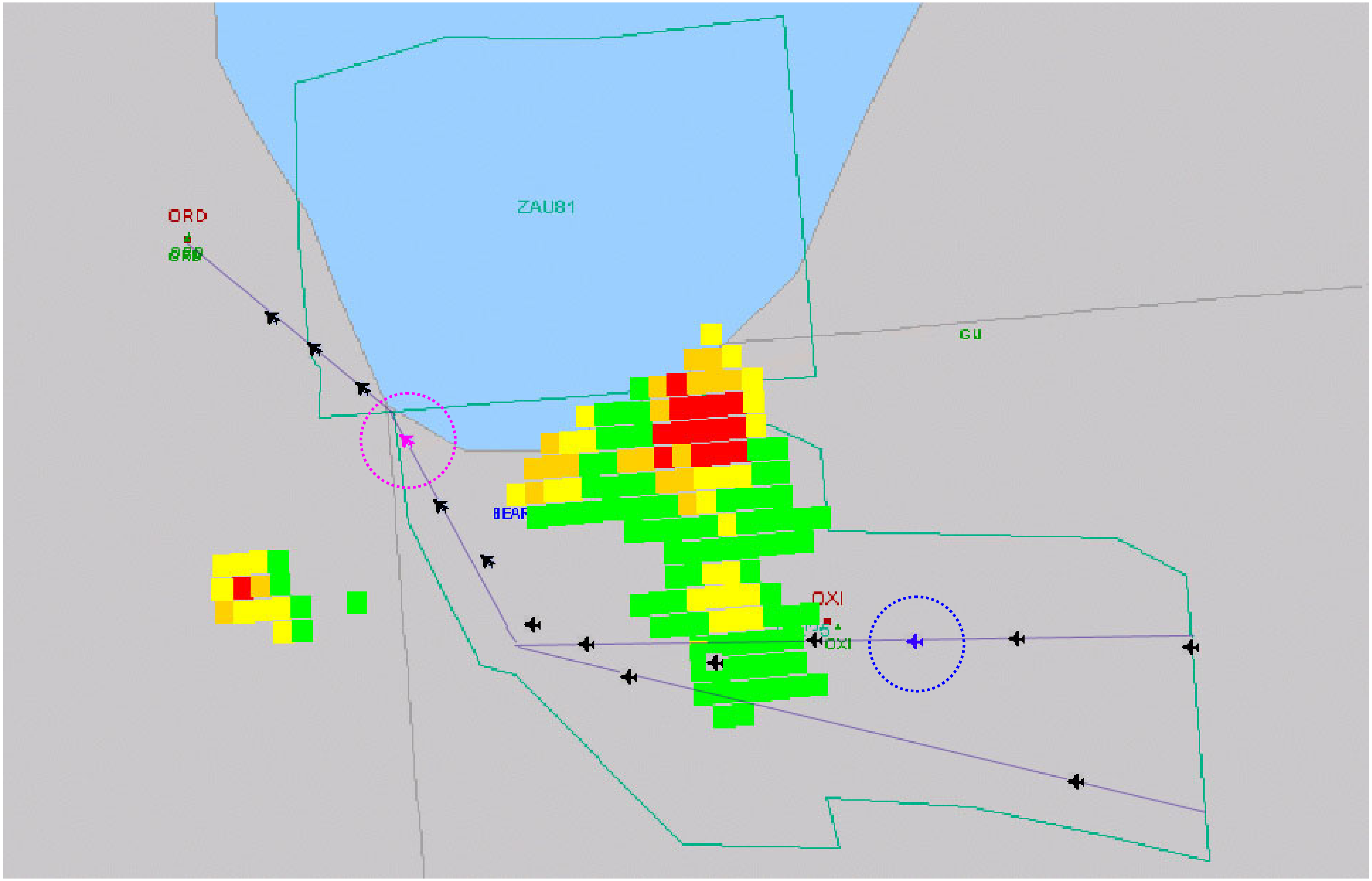
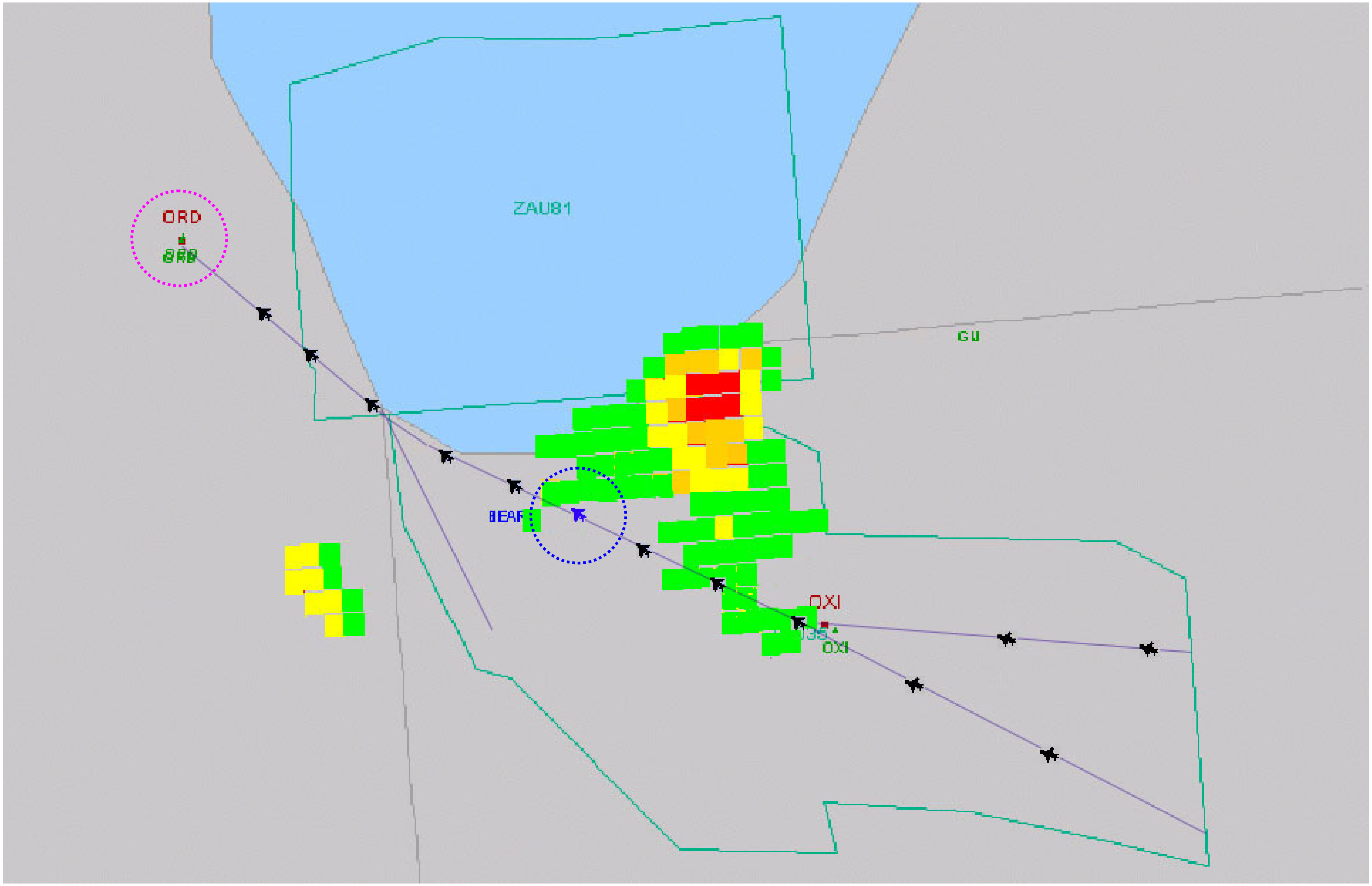
Example Transition Airspace (3)



Example Transition Airspace (4)



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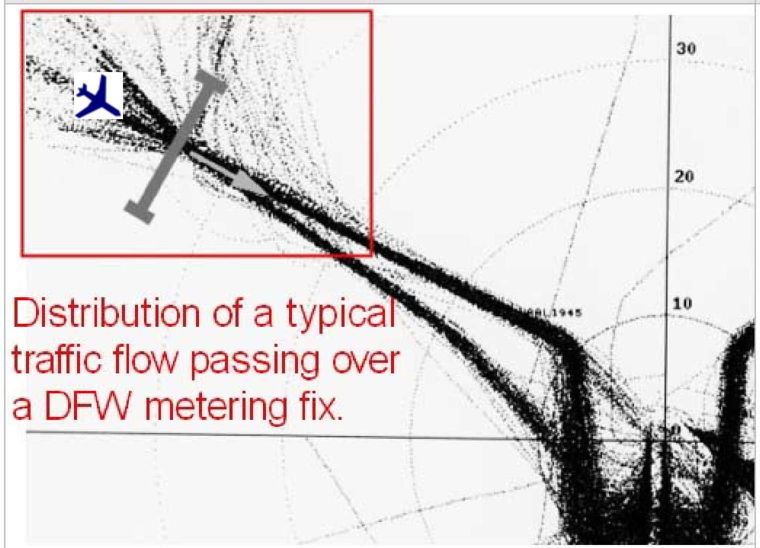
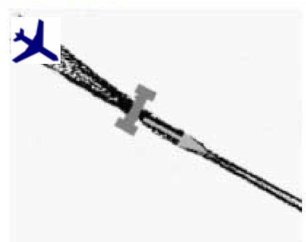
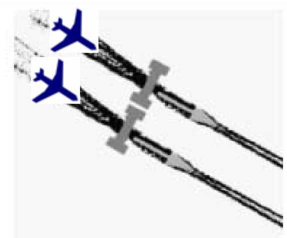
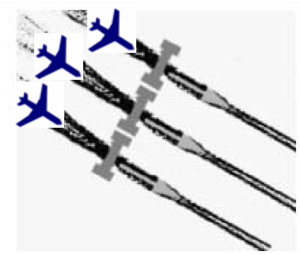
Concept: Single, Double, Triple Metering Fixes

- **2x Throughput: Use Double Metering Fixes**
- **3x Throughput: Use Triple Metering Fixes**
- **Blend concept with TACEC**

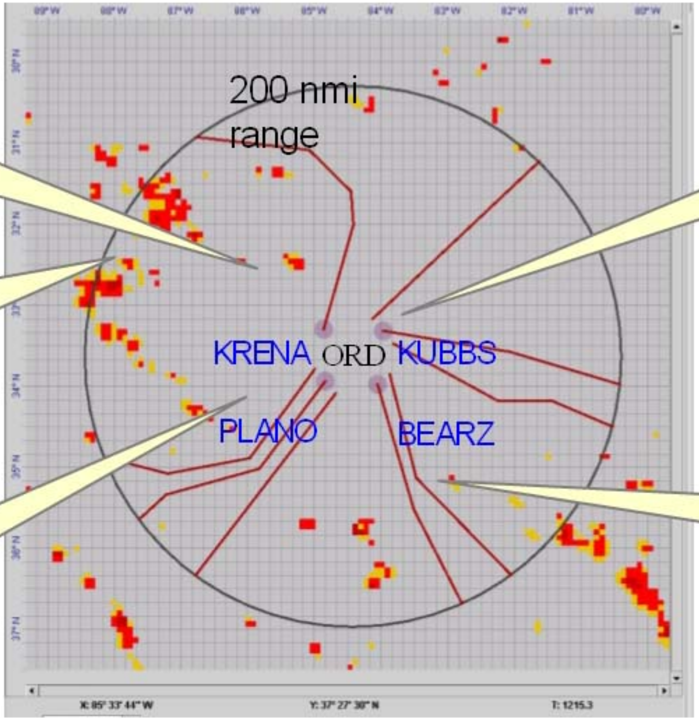
Today	**Future**		
 Distribution of a typical traffic flow passing over a DFW metering fix.	 Single Metering Fix; *Variance of incoming flow reduced by FD precision guidance*	 Double Fix; *Two non-intersecting flows arrive at the metering fix location; requires precision guidance*	 Triple Fix; *Three non-intersecting flows arrive at the metering fix location; requires precision guidance*

Method 2: Non-Intersecting Parallel Flows to Single, Double, or Triple Metering Fixes

1 route synthesized to direct traffic to KRENA.

Only arrival routes and hazardous weather displayed in this image.

3 routes synthesized to direct traffic to PLANO.



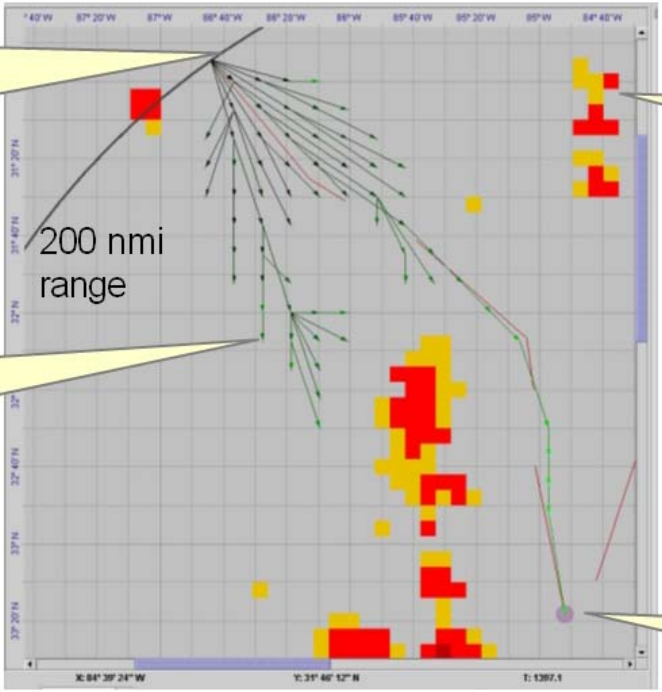
3 routes synthesized to direct traffic to KUBBS.

2 routes synthesized to direct traffic to BEARZ.

Method 3: Free Flight to Single, Double, or Triple Fixes

The Free Flight route starts at the point where the aircraft arrived on the experiment day.

The search terminates here due to hazardous weather.

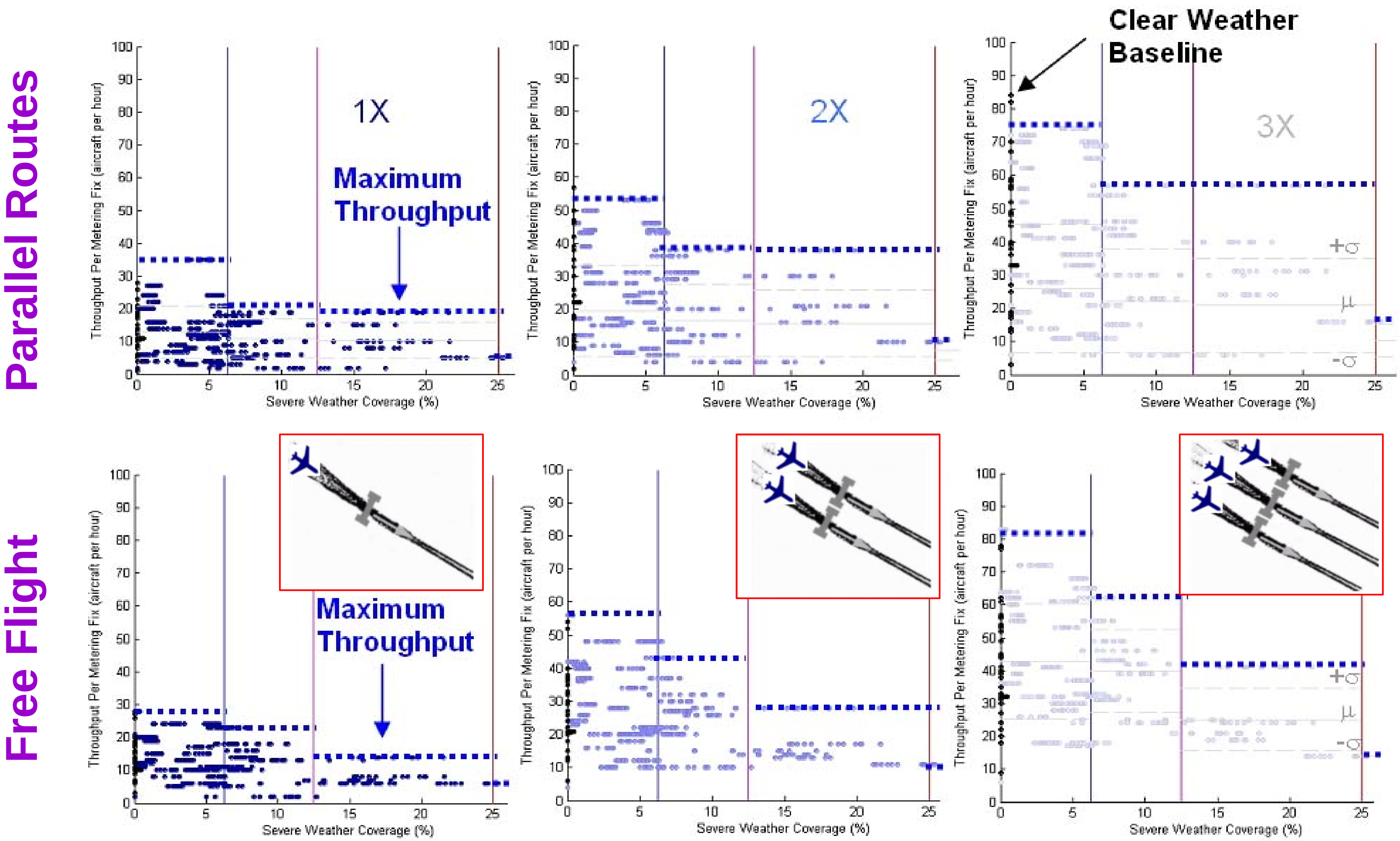


Only hazardous weather is displayed in this image.

A search in space-time (Space-Time Flow (STF) method) used to avoid aircraft already within the transition airspace, along with avoiding severe weather.

The search ends at the airport metering fix location.

Comparison: Parallel Jet Routes vs Free Flight to Single, Double, or Triple Fixes



Core Idea 1.4 –
Weather Avoidance Algorithms for Transition Airspace

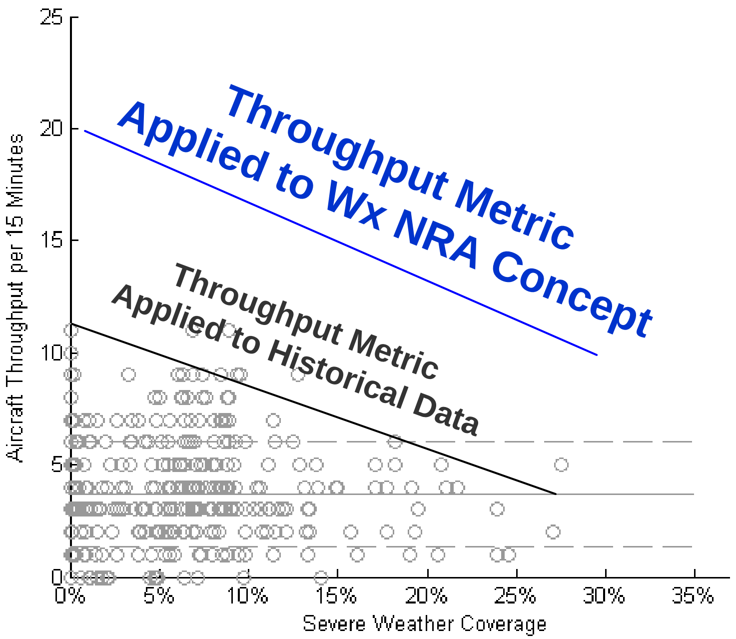
- **Determine lost arrival fix capacity from weather coverage in transition airspace (weather severity index)**

  Typical meter fix throughput (w/o concept):

  capacity = 11 – 27.5 * WSI (per 15 minutes per arrival fix)

  Average weather avoidance algorithm:

  capacity = 20 – 50.0 * WSI



- **Limit airport AARs by maximum meter fix throughputs**
- **Use AirportState data file to create associated XFR airport states**

Relevant Metrics:

- **Delay**

Time-of-arrival statistics are likely the only metrics well-matched to the fidelity of the ACES simulation

Pushback Delay = Actual Gate Departure Time – Scheduled Gate Departure Time

Taxi Out Delay = Actual Takeoff Time – Scheduled Takeoff Time – Pushback Delay

Airborne Delay = Actual Landing Time – Scheduled Landing Time – Taxi Out Delay – Pushback Delay

Taxi In Delay = Actual Gate Arrival Time – Scheduled Gate Arrival Time – Airborne Delay – Taxi Out Delay – Pushback Delay

Total Delay = Actual Gate Arrival Time – Scheduled Gate Arrival Time

Additional Metrics:

- **Airport Efficiency**

Indicator of how well departure and arrival demand is being serviced

$$departure\ efficiency = \frac{1}{N}\sum_{n=1}^{N}\frac{departure\ throughput}{\min(ADR,\ departure\ demand)}$$

$$arrival\ efficiency = \frac{1}{N}\sum_{n=1}^{N}\frac{arrival\ throughput}{\min(AAR,\ arrival\ demand)}$$

- **Weather Exposure**

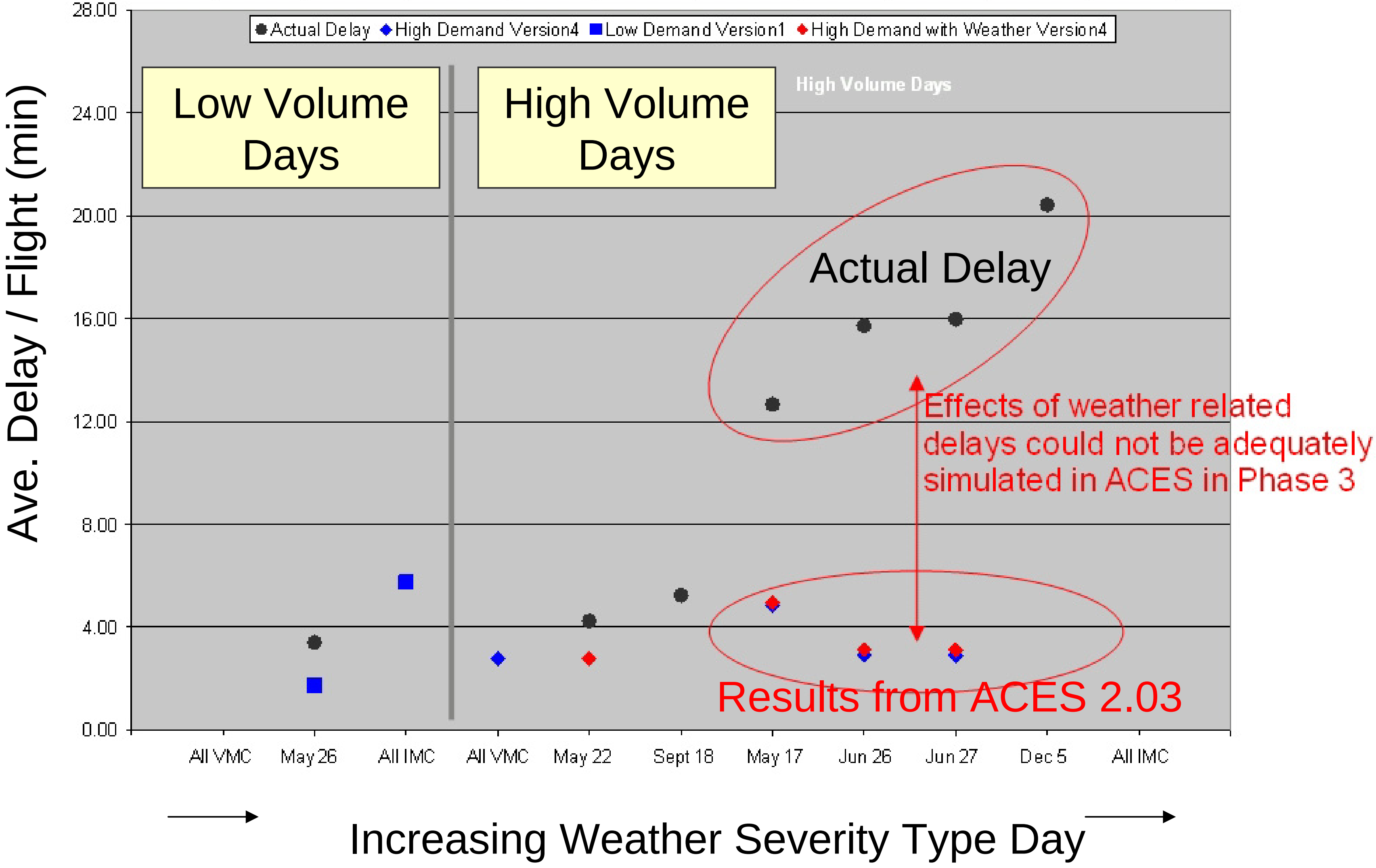
Duration of penetration into severe weather (NWS level 3 and above)

$$exposure = \int_{t_{off}}^{t_{on}} w_n\, dt \qquad w_n = \begin{cases} 0, & \text{for } n = 0,1,2 \\ 1, & \text{for } n = 3,4,5,6 \end{cases}$$

Phase 3 Results:

- **Completed 50 NAS wide ACES B2.03 simulation runs for 2002**
  - **Best case / worst case runs (all VMC state or all IMC state) for 2002**
  - **Baseline runs (ASPM VMC/IMC state) for all 2002 days**
  - **GDP/Wx runs (ASPM VMC/IMC state plus GDP capacities) for all 2002 days**
- **Completed 1 NAS wide ACES B2.03 simulation run for 2020**
  - **Baseline run (ASPM VMC/IMC state plus OEP capacities) for May 17, 2020**
- **Added model of weather severity index to ACES**
  - **Functions to ingest reflectivity data into ACES**
  - **Functions to calculate airport and sector weather coverage values**
  - **Functions to display reflectivity data on VST**

Phase 3 Results



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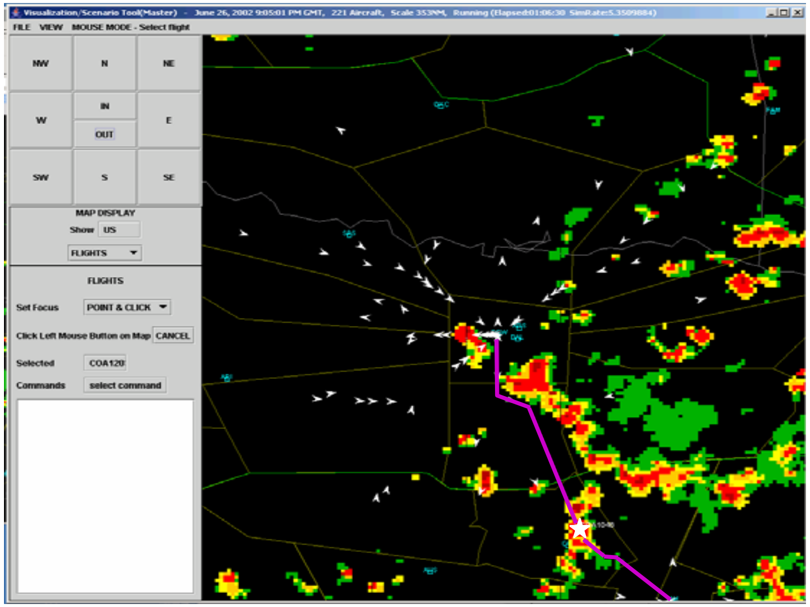
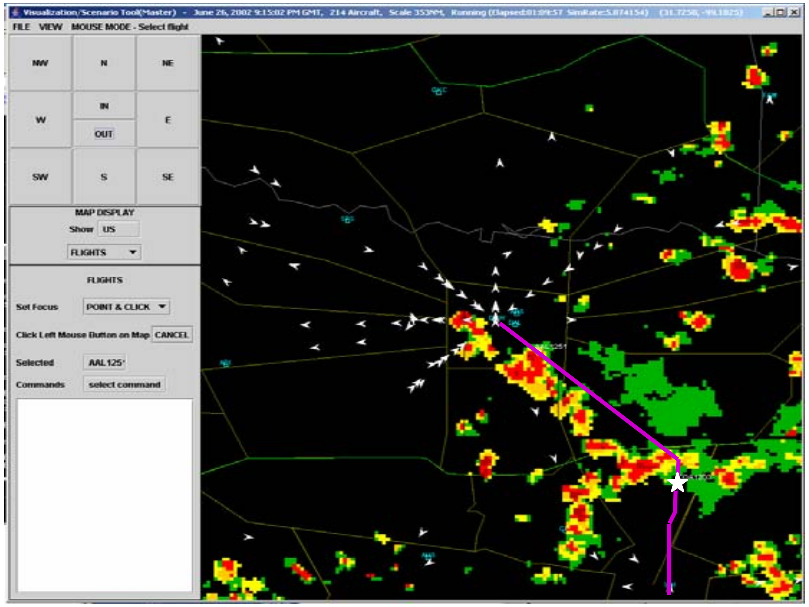
Display of Weather Reflectivity on VST:

Example 1:
Departure flight penetrating Level 6 Weather





Example 2:
Arrival flight penetrating Level 5 Weather

Issues:

- ACES Flight Data Sets (FDS) have significant demand shortfall with respect to total operations reported by ASPM
  - High volume scenario (5/17/2002) has 55,399 (ASPM) vs 40,496 (ACES)
  - Low volume scenario (5/26/2002) has 40,775 (ASPM) vs 30,220 (ACES)
  - All future scenarios are derived from these two baselines
- ACES takes a significant time to run a NAS-wide scenario
  - Execution time does not scale linearly with number of Generic Masters
  - Single machine runs are limited to regional simulations (1000-2000 flights)
- ACES poses a significant burden on disk space and network utilization
  - Size of output data scales almost linearly with number of flights

Issue:

- **Perform an Annualization based on the no weather days and low weather days for now, and later include the moderate and severe weather days when ACES models improve**

Learn what we can about trends with our latest version of ACES

$$\text{Annualized Cost} = \underbrace{0.338C_1()}_{\text{Type 1 Days}} + \underbrace{0.268C_2()}_{\text{Type 2 Days}} + \underbrace{0.166C_3()}_{\text{Type 3 Days}} + \underbrace{0.130C_4()}_{\text{Type 4 Days}} + \cancel{\underbrace{0.063C_5()}_{\text{Type 5 Days}}} + \cancel{\underbrace{0.025C_6()}_{\text{Type 6 Days}}} + \cancel{\underbrace{0.010C_7()}_{\text{Type 7 Days}}}$$

Cluster	Cluster Name	Number of Days 2002	Number of Days 2003	Number of Days Total	Frequency (%) 2002	Frequency (%) 2003	Frequency (%) Total
1	Clear Weather High Volume Type Day	125	122	247	34.2	33.4	33.8
2	Clear Weather Low Volume Type Day	113	83	196	31.0	22.7	26.8
6	Moderate Weather Low Volume Type Day	45	76	121	12.3	20.8	16.6
3	Moderate Weather High Volume Type Day	58	37	95	15.9	10.1	13.0
~~4~~	~~Severe Weather with Low GSs; High GDPs~~	~~14~~	~~32~~	~~46~~	~~3.8~~	~~8.8~~	~~6.3~~
~~5~~	~~Severe Weather with High GSs; Low GDPs~~	~~9~~	~~9~~	~~18~~	~~2.5~~	~~2.5~~	~~2.5~~
~~7~~	~~Severe Weather with High Cancellations~~	~~1~~	~~6~~	~~7~~	~~0.3~~	~~1.6~~	~~1.0~~

Lessons Learned:

- Computer Hardware Availability was the single biggest limiting factor with regard to the number of simulations completed
- 49 ACES simulation experiments required more than 1100 hrs (approximately 45 days) of computation time to complete
- Each simulation required an additional 2 - 4 hours to prepare the input files, configure the simulations, collect the output files and import the results into a MySQL database
- No 2020 simulation (2X 2002) demand could be run on the machines at Metron Aviation simply due to Memory Limitations
- The 2020 (2X 2002) demand set required over 70 hrs of computation time to complete even on a set of 10 machines

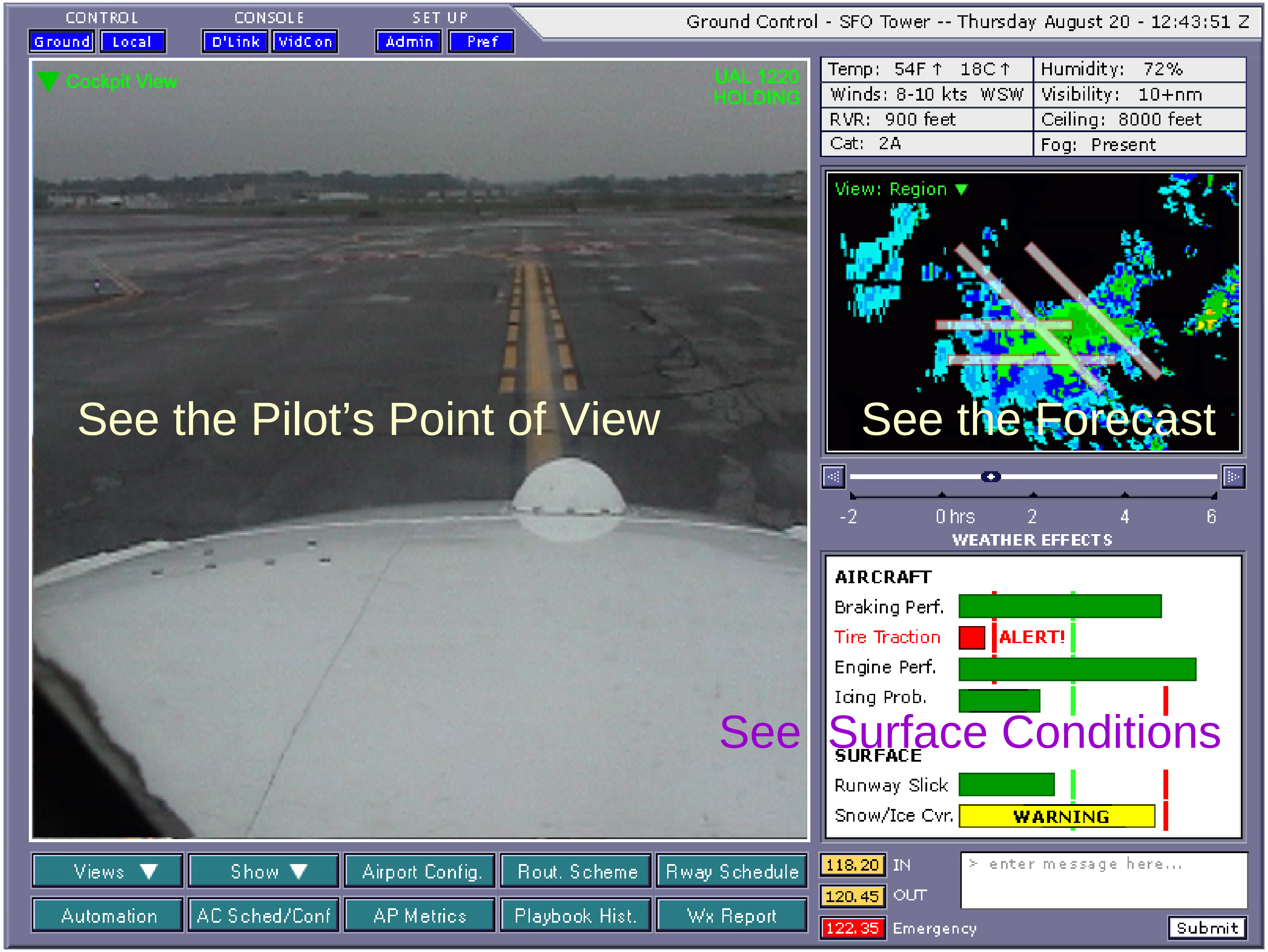
Challenges

- **Model Weather Reroutes such that we observe a "quadratic like" trend in weather related delays with increasing weather severity days**
- **GDPs tradeoff ground delay vs airborne delay:**
  - **How do we model the most promising GDP methods in future ACES Builds?**
  - **What about FCA-Based GDPs?**
- **ACES Requirements are varied:**
  - **Rerouting essential**
  - **Playbook Plays highly desired**
  - **Mechanisms to support GDPs highly desired**
  - **Wind Optimized routing desired**
  - **Some ability to link delays and cancellations with line of flight preferred**

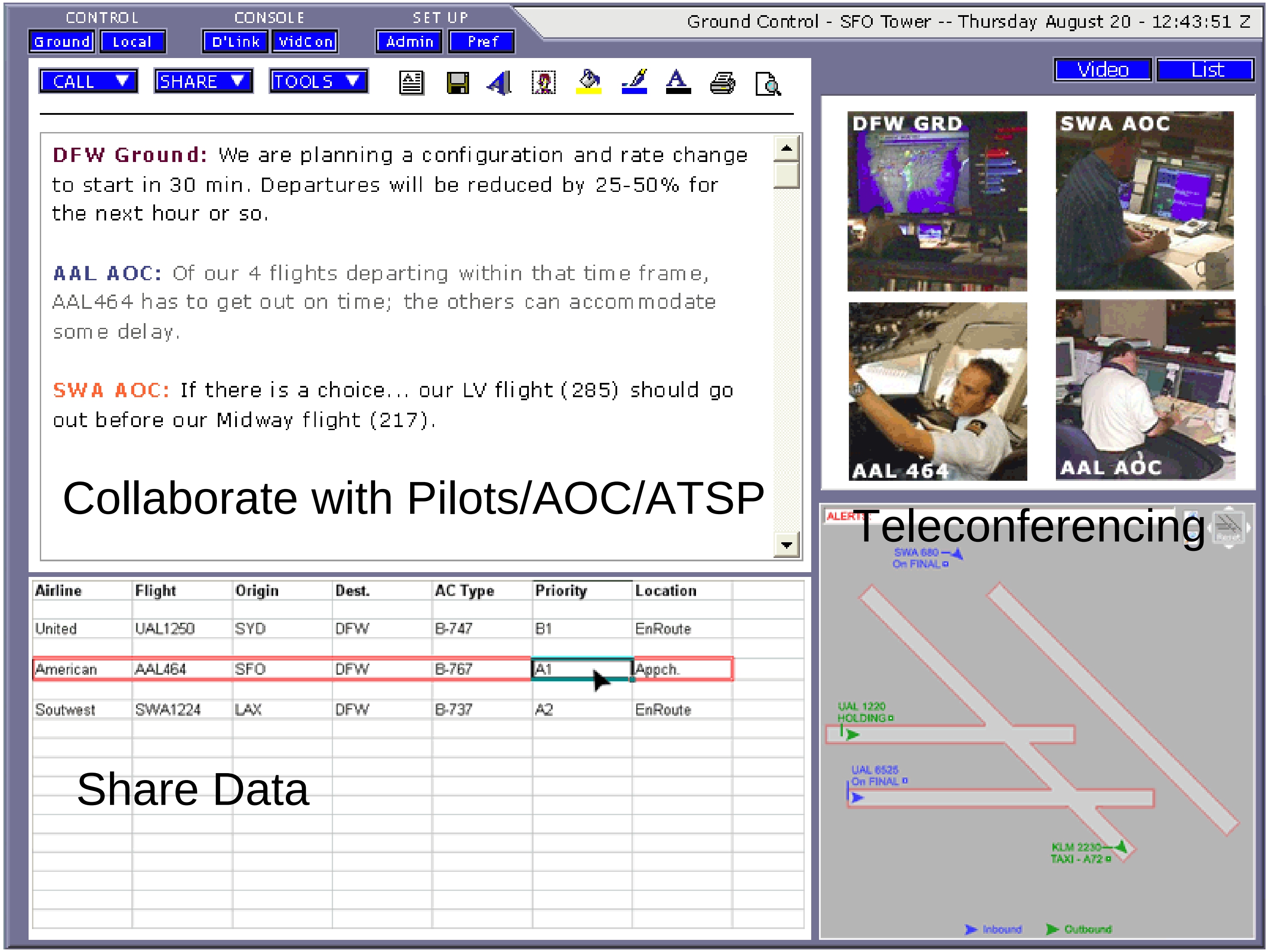
Challenges

- We must consider Human Factors limitations to the blended operational concepts
- Use Cases from higher level blended Core Ideas are needed
- Distributed Work Systems and Procedures need to be developed to end up with a viable Blended Concept – Need to avoid excessive cognitive complexity and workload for any one individual in the system
- Need to Paint a Picture of how this is going to all work

Local/Ground Controller



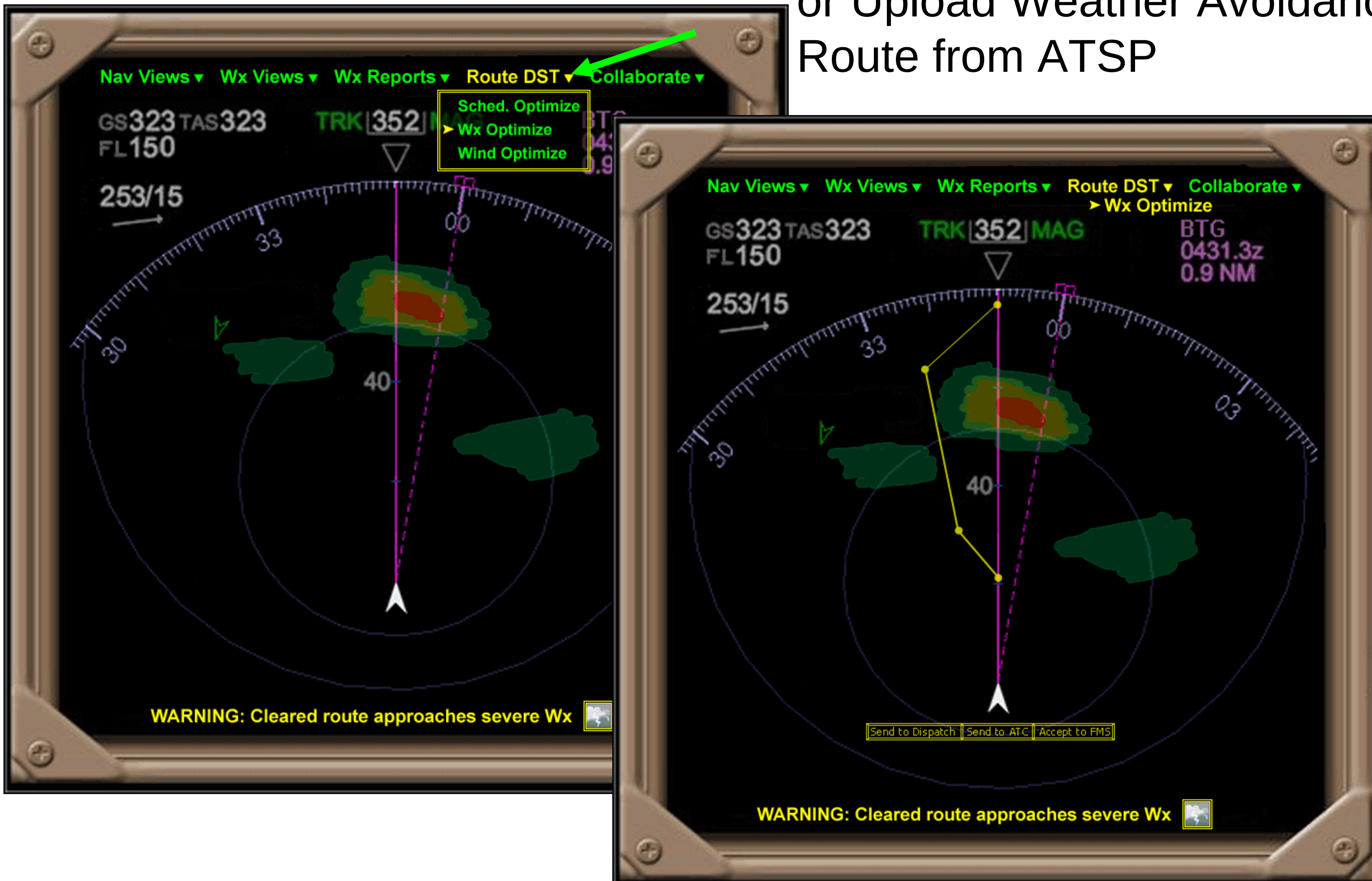
Local/Ground Controller



Airline	Flight	Origin	Dest.	AC Type	Priority	Location
United	UAL1250	SYD	DFW	B-747	B1	EnRoute
American	AAL464	SFO	DFW	B-767	A1	Appch.
Soutwest	SWA1224	LAX	DFW	B-737	A2	EnRoute

Pilot/Cockpit

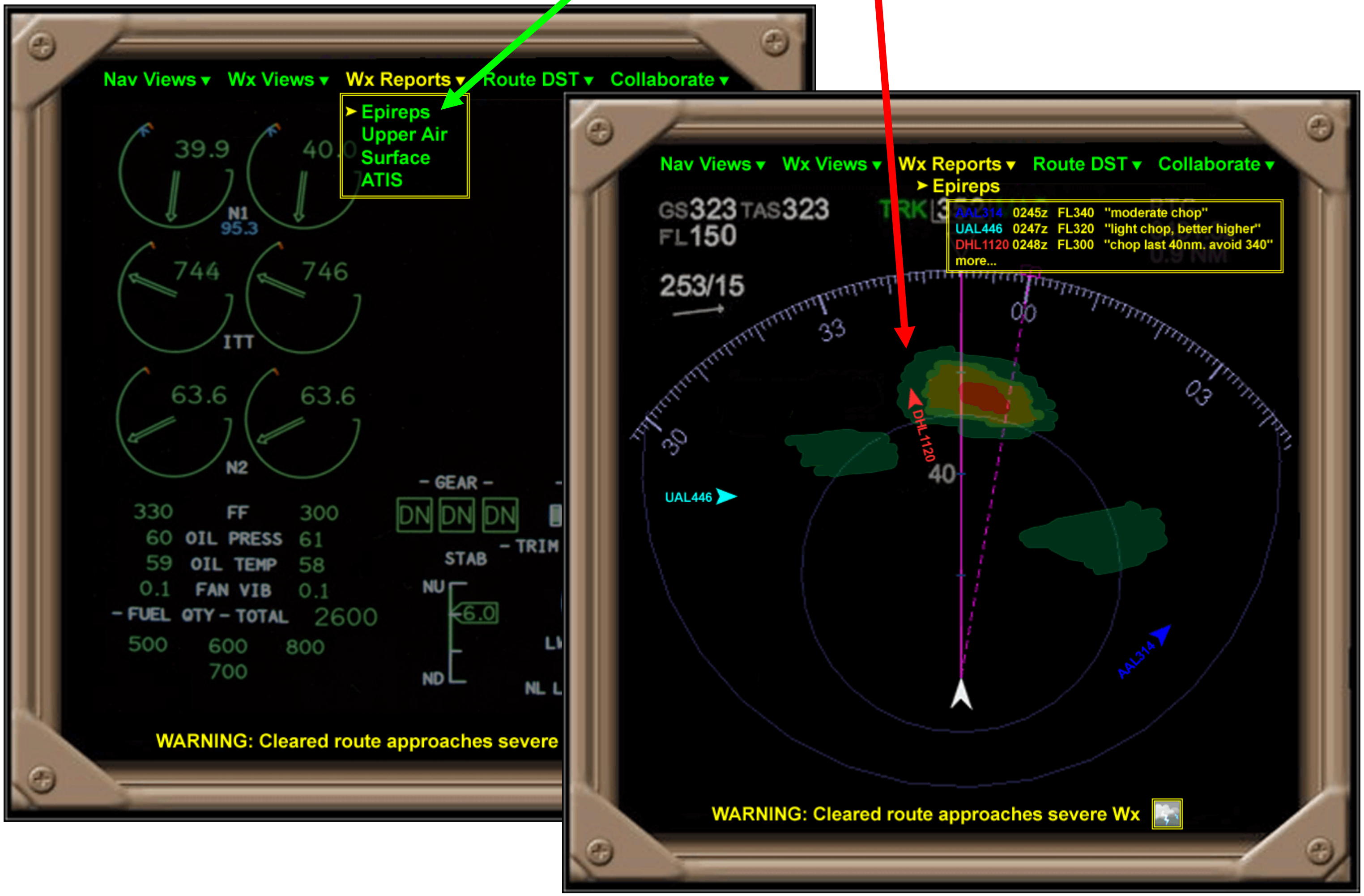
Optimize Route for Free Flight or Upload Weather Avoidance Route from ATSP



METRON AVIATION

Pilot/Cockpit

View E-PIREPS from Nearby Aircraft



Pilot/Cockpit

Join a Collaboration Conference

METRON AVIATION

Point of Contact